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Airfield Damage Repair Civil Engineer Modernization Program

Laboratory and Field Evaluation of Rapid Setting Cementitious Materials for Large Crater Repair

Lynette A. Barna, Jeb S. Tingle, and Patrick S. McCaffrey

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Abstract: Current practice for expedient runway repair dictates capping either a crushed stone or sand grid repair with a foreign object damage (FOD) cover. In recent testing, the heavy loading characteristics of transport aircraft have been shown to reduce the performance life of these types of repairs. Repairs capped with concrete are limited by time requirements, equipment, and available materials. Short set times, rapid strength gain, good durability, and satisfactory flexibility to resist the punishment of repeated heavy aircraft loads are beneficial characteristics of rapid setting cementitious materials. However, the use of these materials has been limited due to short working times, health concerns, and excessive shrinkage cracking. Improvements in rapid setting materials have allowed their use to become more common in pavement construction and repair projects, particularly when the operational tempo is critical to avoid penalty. Numerous commercial products are available. A full-scale field test was conducted using rapid setting materials to repair simulated bomb craters in an airfield. The repaired sections cured for 4 hr and were trafficked using a load cart equipped with an F-15E aircraft tire. The target service life of the repair was between 100 and 5,000 passes of the load cart. Results from this study were incorporated into Air Force guidance addressing the use of rapid setting materials for crater repair. This report describes the repair methods and performance of the rapid setting materials used in the full-scale field test to repair large craters.

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Preface

This report was developed for use by the U.S. Air Force, base civil engineers, major command pavement engineers, RED HORSE (Rapid Engineer Deployable Heavy Operations Repair Squadron Engineer) units, and Prime BEEF (Base Engineer Emergency Force) units. Additional users include the Army, Navy, and Marine Corps units charged with an airfield damage repair (ADR) mission.

The project described in this report is part of the ADR Civil Engineer Modernization program currently sponsored by Headquarters, Air Combat Command (HQ ACC), Langley Air Force Base (AFB) and managed by the Air Force Civil Engineer Support Agency (AFCESA). Guidance was provided by Joe Fisher, HQ ACC/A7X, Langley AFB, VA and George Vasteenburg, AFCESA/CEOP, Tyndall AFB, FL.

This publication was prepared by personnel of the U.S. Army Engineer Research and Development Center (USAERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH and Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented in this report are based upon a series of laboratory tests conducted at ERDC in Vicksburg, MS and field tests conducted at the Silver Flag Exercise Site, Tyndall AFB, FL from February to September 2006. The principal investigator for this study was Lynette A. Barna of the Force Projection and Sustainment Branch (FPSB), CRREL. The lead technician was Patrick S. McCaffrey of the Airfields and Pavements Branch (APB), GSL. The program manager was Jeb S. Tingle of the APB, GSL. Numerous ERDC personnel assisted in this study. Laboratory testing of the cementitious materials was supported by the Concrete and Materials Branch (CMB), GSL. Technical assistance was provided by the Engineering Resources Branch (ERB), CRREL, and the Instrumentation Systems Division of the Information Technology Laboratory (ITL), Vicksburg. Photographic and video documentation was provided by Alan Middleton and Oscar Reishmann, ITL.

This report was prepared by Barna (CRREL), Tingle and McCaffrey (GSL). The work was conducted under the supervision of Don R. Alexander, Chief, APB; Dr. Larry N. Lynch, Acting Chief, Engineering Systems and

Materials Division; Dr. William P. Grogan, Deputy Director, GSL; and Dr. David W. Pittman, Director, GSL.

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COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

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Unit Conversion Factors

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	3.93701×10^{-2}	inches	in.
cm	centimeters	3.93701×10^{-1}	inches	in.
m	meters	3.28084	feet	ft
m	meters	1.09361	yards	yd
km	kilometers	6.21371×10^{-1}	miles (statute)	mi
		Area		
mm^2	square millimeters	1.55000×10^{-3}	square inches	$In.^2$
m^2	square meters	1.07639×10^{1}	square feet	ft^2
m^2	square meters	1.19599	square yards	yd^2
		Volume		
mL	milliliters	3.38140×10^{-2}	fluid ounces	fl oz
L	liters	2.64172×10^{-1}	gallons	gal
m^3	cubic meters	3.53147×10^{1}	cubic feet	ft^3
m^3	cubic meters	1.30795	cubic yards	yd^3
		Mass		
kg	kilograms	2.20462	pound-mass, avoirdupois (avdp)	lbm
g	grams	3.52740×10^{-2}	ounces (avdp)	oz
		Density		
kg/m^3	kilograms per cubic meter	1.68555	pound-mass (avdp) per cubic yard	lbm/yd^3
kg/m^3	kilograms per cubic meter	6.24280×10^{-2}	pound-mass (avdp) per cubic foot	lbm/ft^3
		Temperature (exact)		
°C	degrees Centigrade	1.8 x (°C) + 32	degrees Fahrenheit	°F
		Pressure or Stress		
MPa	megapascals	1.45038×10^{2}	pound-force per square inch	psi

Nomenclature

Abbreviation	
ACI	American Concrete Institute
ADR	airfield damage repair
AFCESA	Air Force Civil Engineer Support Agency
AFRL	Air Force Research Laboratory
APB	Airfields and Pavements Branch
ASTM	American Society for Testing and Materials
CBR	California bearing ratio
CMB	Concrete and Materials Branch
COTS	commercial off-the-shelf
CRREL	Cold Regions Research and Engineering Laboratory
DCP	dynamic cone penetrometer
ERB	Engineering Resources Branch
ETL	Engineering Technical Letter
FOD	foreign object damage
FPSB	Force Projection and Sustainment Branch
GSL	Geotechnical and Structures Laboratory
HQ ACC	Headquarters, Air Combat Command
HWD	heavy weight deflectometer
ITL	Information Technology Laboratory
NATO	North Atlantic Treaty Organization
NDT	non-destructive testing
OPC	ordinary portland cement
Prime BEEF	Base Engineer Emergency Force
PSPA	portable seismic pavement analyzer
RED HORSE	Rapid Engineer Deployable Heavy Operations Repair Squadron Engineer
RS	rapid setting
USACE	U.S. Army Corps of Engineers
USAERDC	U.S. Army Engineer Research and Development Center

1 Introduction

Background

In 1940, Prime Minister Winston Churchill wrote to the Secretary of State for Air that “All craters should be filled in within 24 hours at most, and every case where a crater is unfilled for a longer period should be reported to higher authorities…” (Stroup et al. 1986). It was recognized that crater repairs required attention of the highest priority to minimize the time an airfield was inoperable. To meet the urgent need for repairs, highly mobile, dedicated teams were trained to perform the repairs using special equipment and available, pre-positioned stockpiles of materials. The current NATO (North Atlantic Treaty Organization) crater repair standard is to recover an airfield for emergency operations within 4 hrs of an attack (Hoff 1975, Stroup et al. 1986).

In early conflicts, aircraft were the intended targets of air attacks until the physical elements of the airfield, such as runways and pavements, were recognized as assets and instead became vulnerable to attack. Unable to take off and land, the opponent’s aircraft were delayed from carrying out retaliatory strikes, thereby providing the attacking force with a clear advantage. For the forces confronting the air attack, the foremost priority is recovering the airfield following the attack as quickly as possible to launch a counter strike.

The problem of rapidly responding to airfield attacks has been investigated since the 1950s. New materials, equipment, and procedures have all have been investigated and used in large-scale field trials with the intent of refining and improving the techniques and resources needed to effectively repair airfield crater damage.

A number of studies have investigated the issue of rapid runway repair. The search continues for the right balance of materials, equipment, and personnel experience to satisfy the increasingly perilous recovery period. While each investigation contributes more to the body of knowledge for bomb damaged airfield repair, there is no single material or technique that stands out as the one solution applicable for all possible scenarios. As new materials and equipment are introduced, they are evaluated for their potential incorporation into crater repair.

Previous studies assessed candidate materials used in field demonstrations, designed to create as realistic conditions as possible, followed by performance testing of the repairs by simulating aircraft traffic through the use of a load cart (McNerny 1980, Hammitt et al. 1986). The use of conventional equipment to complete the repairs not only reduces the extra space and weight needed to airlift special equipment into theater, but also reduces the need for special parts and maintenance, and extra troop training. Previous field trials have utilized conventional construction equipment to show that significant changes to placement procedures would not be required (Hoff 1975, Sugama et al. 1984). Other studies were dedicated to reducing the repair time by using efficient and improved techniques with the conventional approach (Beyer and Bretz 1981, Hokanson and Rollings 1975, Hokanson 1975). In other studies, nonstandard equipment was used to test continuous mixing procedures and adapt equipment not typically used for crater repair (Hoff 1975, Hammitt et al. 1986).

Even today, the established repair method involves backfilling the bottom of the crater with the surrounding ejecta to fill as much of the void as possible. Aggregate is placed as a subbase layer and compacted flush with the existing surface, and the repair is capped and secured with a landing mat. The idea of a structural cap was intended to replace either a portion of or all of the aggregate layer to reduce the equipment and manpower needed to place and compact the material and set the mat. Use of cementitious materials would simplify placement, as the material would be more fluid, and provide ease of leveling the final surface compared with landing mats. The characteristics of high-early strength rigid materials were deemed an valuable quality for potential materials used for the structural cap (Boyer et al. 1982). Some of the early materials studied for use as a structural cap to support aircraft loads included regulated cement (Hoff 1975, Hammitt et al. 1986), high-early strength concrete (Hammitt et al. 1986), polymer concrete (McNery 1980, Fowler et al. 1982, Kubo et al. 1986, Beyer and Bretz 1981), and polyurethane resin (Kubo et al. 1986). Laboratory testing was conducted to characterize the candidate materials for critical properties, such as strength, prior to using them in the field (Fowler et al. 1982). Many of the earlier materials were dismissed due to their toxicity to both humans and the environment.

Many factors are considered when determining an appropriate repair method for bomb damaged runways including the type of aircraft and aircraft design weight, the availability and quality of the repair materials,

the existing equipment, and the amount of time to complete the repair. Among the available options for expedient runway repairs, none are suitable for both heavy cargo and fighter aircraft, with the exception of the use of rapid setting (RS) cementitious materials. Even though these materials are included in the repair options, their usage is restricted to spall repair. Large craters are defined as damage to the airfield pavement that penetrates into the base course layer with an apparent diameter in excess of 20 feet (U.S. Army Corps of Engineers 2002).

Numerous rapid setting concrete repair materials are now commercially available that feature short set times, high early strength, good flexural strength and durability characteristics. Their ability to re-open traffic in short timeframes and support heavy loads also are favorable characteristics. While many of these products have been successfully used in the transportation industry, they require testing for application to the unique requirements of large bomb-damaged airfield craters.

Project description

In support of the U.S. Air Force Air Combat Command, Airfield Damage Repair Civil Engineer Modernization Program, the U.S. Army Engineer Research and Development Center (ERDC) tested and evaluated alternative materials and methods to rapidly repair large bomb craters on airfields. This investigation surveyed the commercial market and selected Rapid Set (RS) products for both laboratory and full-scale field testing. Laboratory testing evaluated the suitability of the selected RS materials for use in repairing damaged airfields and was based on a test protocol developed for the acceptance of repair materials for rigid spall repairs. The laboratory tests were conducted at the Geotechnical and Structures Laboratory (GSL) in Vicksburg, MS. Full-scale field tests were conducted at the Silver Flag Exercise Site in cooperation with the Air Force Civil Engineer Support Agency (AFCESA) and the Air Force Research Laboratory (AFRL) at Tyndall AFB, FL. Simulated large craters were constructed and repaired using the RS materials. Following completion of the repair, the test craters were subjected to dynamic loading with a load cart. The results from both the laboratory and field portions of this investigation will be used to further develop methods for rapidly repairing large bomb craters in airfield pavements.

This project evaluated commercial off-the-shelf (COTS) RS materials using existing techniques and equipment to rapidly repair large craters and

damaged pavements on runway surfaces. Detailed guidance is provided on potential solutions that provide pavement repairs capable of supporting between 100 and 5,000 passes of heavy cargo and fighter aircraft, within an acceptable timeframe. This effort quantifies the expected service life of the repair material using accepted methods or procedures modified as appropriate. The product of this project is guidance on an interim solution for capping large craters that establish a baseline for the development of advanced ADR methods.

Project objectives

The objectives of the project are to:

a. Identify and evaluate, through laboratory testing, the material specifications and suitability of the use of RS materials in a large volume expedient runway repair application;
b. Utilize RS materials with existing equipment and placement methods in a large-scale field application;
c. Evaluate the appropriateness of using existing equipment and techniques to mix and place RS materials;
d. Dynamically load early-age repaired craters with a load cart equipped with an F-15E tire and evaluate the performance of the RS materials;
e. Provide guidance for the use of RS materials to rapidly repair damaged runways and restore aircraft operations within an acceptable timeframe.

Project scope

This project tested commercially available rapid setting cementitious materials for use with existing techniques for the rapid repair of large craters and damaged pavements on runway surfaces. To reduce the equipment footprint, portable mixing equipment was tested for compatibility with rapid setting materials and to determine the impacts on the repair process. Specifically, detailed guidance will be provided on potential solutions that will provide pavement repairs capable of supporting both heavy and fighter aircraft with an objective timeframe of 4 hr.

2 Technical Approach

Introduction

Following an enemy attack, the critical mission becomes restoring the operational capability of an airfield runway into launch and recover mode in the shortest amount of time possible. This was the experimental scenario applied in this investigation, with the objective being to restore the operational capability to a minimum threshold of 100 passes and an objective of 5,000 passes for the designated aircraft, the F-15E, operating at its mission weight. The timeframe within which to achieve the operational capability of the airfield is 4 hr. By definition, a large crater has an apparent diameter in excess of 20 ft with damage resulting from the impact that penetrates through the pavement and base layers into the subgrade material. Given that the depth and extent of damage that characterizes a large crater may be substantial, the focus of this investigation was limited to the material used as a structural cap. As a result, simulated test craters were constructed for this assessment that intentionally minimized the disturbance of the underlying material layers.

As with any horizontal construction project, large crater repair integrates the concepts of design, material properties, and construction practices. In an attempt to apply these basic concepts to large crater repair in the theater of operations, significant limitations are encountered including: the lack of locally available high quality materials, the limited availability of conventional mixing equipment or mixing equipment not requiring specialized training, inexperienced personnel, and the critical time element under which the operational ability of an airfield must be restored.

Current commercially available material technology was identified through a market survey. Participating vendors in the study were granted latitude, with ERDC oversight, in their approach for crater repair. The vendors elected which of their products would be suitable for the repair. In general, the equipment used to conduct the repairs was consistent with the current Air Force inventory as given in existing ADR criteria (U.S. Army Corps of Engineers 2002). To complete a repair of this size within the expected timeframe, the small portable mixers listed in the inventory are simply inadequate. For this reason, a larger capacity, horizontal shaft,

portable mixer was substituted as the standard mixer. A standard ready-mix truck was available strictly as backup in case the portable mixer stopped working. Outside of this, any specialized equipment required to conduct the repair was arranged by the material vendor. In addition to providing products and equipment for field testing, the vendors furnished the same RS product for laboratory testing.

Laboratory testing and large-scale field testing played significant roles in this investigation. To determine the suitability of a RS material for use in crater repair, the laboratory test matrix was based on the guidance in *ETL 08-2: Testing Protocol for Rigid Spall Repair Materials* (U.S. Air Force 2008a). The set of laboratory tests selected to characterize the RS materials is described in the section designated Laboratory Testing.

In the large-scale field testing, the RS test materials were used to repair simulated large craters. Six test craters were constructed and repaired using the RS test materials at a suitable runway site. A stone and grout repair method, an accepted approach for an expedient/sustainment repair, served as a control section. After a brief curing period, traffic was applied with a load cart following each repair. Each test crater was instrumented with temperature, moisture, and pressure sensors to provide performance data under dynamic loading conditions. Temperature sensors were installed in the rigid cap to record a thermal history of the RS material as it hydrated. Since the repairs to the test craters were completed in multiple small batches, instead of a standard monolithic pour, the thermal history may provide some insight into the effects of batching. Moisture sensors were installed in the base layer to monitor the shallow water table present at the test site location. The extent to which stress is distributed to the underlying pavement layers was measured using pressure sensors, installed in the traffic lane directly below the RS cap.

Test materials

There are a number of products available on the commercial market used to repair pavement surfaces. Many products have been used successfully on airfields to repair spalls and other small volume repairs. The challenge in this project was using RS materials to repair a large volume, approximately 23 yd^3, as required for large craters. The RS materials tested during this project were (listed in no particular order):

Rapid Set DOT Cement

Rapid Set® DOT Cement is manufactured by CTS Cement. It is a proprietary calcium sulfoaluminate based cement (CTS Cement, Product Datasheet), with fast setting, low-shrinkage properties useful for repairs ranging in depth from 2 to 24 in (CTS Cement, Product Specification sheet). The material is useful for the repair of horizontal structures, such as pavements and bridge decks. This material consists of cement only and must be extended by adding locally available sand and coarse aggregate at the time of mixing.

Pavemend EX-H™

Pavemend EX-H™ is manufactured by CeraTech, Incorporated. The Pavemend family of products are described as, "non-traditional cementitious materials," (CeraTech, Inc. Products Information Sheet). The EX-H material used in this study was a magnesium phosphate based cement. The material is suitable for large area concrete repair and must be extended with coarse aggregate. The 'H' designation is for use at high temperatures, with a surface temperature range from 80 to 120 °F, according to the product literature.

ThoRoc™ 10-61 Repair Mortar

ThoRoc™ 10-61 Repair Mortar is manufactured by BASF (formerly Degussa Building Solutions). It is a rapid setting single-component proprietary hydraulic cement-based mortar that offers an extended working time (BASF ThoRoc 10-61 Product Datasheet). It is useful for horizontal concrete surfaces and may be extended using 3/8 in aggregate.

Ultimax™ Concrete

The Ultimax™ Concrete product manufactured by Ultimax Corporation is a rapid hardening hydraulically-based cement (Ultimax Concrete product literature). It is an all inclusive mix, prepackaged with both the fine and coarse aggregates. Mixing water is added to the material.

Ultimax™ Aquacrete

This was a new, proprietary product developed by Ultimax Corporation that was highly fluid and designed to be used with pre-placed aggregate.

The concept being that once the aggregate was placed, the Aquacrete would fill in the void spaces between the aggregate and set quickly.

3 Laboratory Testing

Introduction

The laboratory testing of the RS materials followed a cementitious materials testing protocol, *ETL 08-2: Testing Protocol for Rigid Spall Repair Materials* (U.S. Air Force 2008a). The test protocol was developed as a method to assess the numerous commercial products available for spall repairs for rigid pavements, and was based on 6 years of laboratory and field experiments conducted during the 1990s by Vaysburd et al (1999). The material test protocol recommended material properties and laboratory tests on spall repair materials with an emphasis on early age specimens. The laboratory testing also served to validate the materials testing protocol for RS repair materials for more than spall repairs.

In this study, the spall materials test protocol was used to test the candidate RS materials to become familiar with their characteristics under controlled conditions and then to compare the laboratory performance with the full-scale field conditions. Ideally, the spall materials test protocol would be used as a method of selecting suitable RS materials that meet the specified material property requirements. However, in this study, all of the candidate RS materials were tested in the full-scale field trial regardless of their performance in the laboratory testing. This allowed us to become familiar with several RS materials which aided in validating and improving the spall materials test protocol.

Although there is a sizeable volume difference between a spall and a large crater, the recommended laboratory tests identified in the spall materials test protocol were still applicable, given the expedient nature of the repair using RS materials. As recommended by the spall materials test protocol, laboratory testing conducted on the candidate RS materials for large crater repair included strength testing (unconfined compression, flexural, and slant shear bond), modulus of elasticity, and time of set (Table 1). One difference in test procedures was the time of set. The protocol recommends ASTM C 191, *Standard test methods for time of setting of hydraulic cement by Vicat needle* (2004), and the RS laboratory testing instead followed ASTM C 403, *Standard test method for time of setting of concrete mixtures by penetration resistance* (2005). The laboratory testing on the RS materials for large crater used those tests listed in the

Table 1. Recommended tests and requirements from spall material testing protocol applied to RS materials for large crater repair.

Spall Material Testing Protocol Recommended Material Tests and Requirements			Large Crater Laboratory Testing[1]	
Material Property	ASTM Test Method	Requirement	Test Ages	Replicates
Compressive Strength	C 39	≥ 3,000 psi at test age of 2 hr ≥ 5,000 psi at test age of 1 day	2 and 6 hr 1 and 28 days	3
Flexural Strength	C78	≥ 350 psi at test ages of 2 hr and 1 day	2 and 6 hr 1 and 28 days	2
Bond Strength by slant shear	C 882	≥ 850 psi (repair to OPC)[2] ≥ 1,000 psi (repair to repair)[3] Test age of 1 day	24 hr and 28 days	2
Modulus of Elasticity	C 469	≤ 3 x 10^6 psi at test age of 2 hr ≤ 4 x 10^6 psi at test age of 3 days	2 and 6 hr 1 and 28 days	3
Time of Setting	C191	No requirement at this time[4] Test begins immediately	ASTM C 403 immediately	2

1 All tests conducted at two temperature conditions ambient (73 °F) and elevated (90 °F).

2 Repair material bonding to ordinary Portland cement mortar.

3 Repair material bonding to repair material.

4 Report initial and final set times in minutes.

spall materials test protocol which were viewed as being most applicable. For this reason, volumetric expansion, shrinkage potential, and freeze-thaw resistance tests were not conducted.

Temperature also plays a role in the workability, strength development, and overall performance characteristics of RS concrete materials. Air temperatures during the full-scale field testing were expected to be warmer than typical ambient laboratory conditions. For this reason, the RS materials were tested at two temperature conditions – ambient (73 °F) and elevated (90 °F). Prior to mixing at either temperature condition, all of the mix materials, to include the mix water, were placed in the mixing room and allowed to equilibrate. At the elevated temperature, the RS materials were mixed and cured in an environmentally controlled chamber.

In accordance with the manufacturer's mixing instructions, locally available, stock aggregates were used to extend mixes. Regular tap water was used for the mix water. The test age was determined from the time that the mix water and the RS material came in contact. Given the rapid setting

nature of some of the test materials, retarding agents were used in the preparation of the mixes to allow more time to cast test specimens. For several of the RS materials, representatives from the respective company were present in the laboratory and provided guidance when the materials were mixed and specimens cast. Details of the mixing procedure and testing results for each test material are included in Appendix A.

The laboratory testing program provided some familiarization with the behavior of the RS materials prior to their use in the full-scale field test. Since the completion of the RS laboratory testing, the spall materials testing protocol has been refined to include flexural strength and time of set among the recommended test procedures, and also advises testing at the temperature expected at the time of placement, to become familiar with how the materials will perform.

Material evaluation tests

Compressive strength

Compressive strength is a common strength property used in verification testing. Cast specimens were tested in accordance with ASTM C 39 (2005), which was modified in this investigation to capture the early-age strength. Early-age strength is specified in the testing protocol (U.S. Air Force 2008a) as early high-strength development is critical for re-opening the airfield to traffic. Laboratory test cylinders were tested at ages of 2 hr, 6 hr, 24 hr, and 28 days. During the mixing process, a retarding agent was used for CTS Cement and both Ultimax products at ambient temperature, and only the CTS Cement RS material at elevated temperature. The strength results from both the ambient and elevated tests are given in Table 2 and Table 3, respectively. Figure 1 shows the average unconfined compressive strength at ambient (a) and elevated (b) temperatures, respectively, with the solid line indicating the recommended strength requirement from the spall material testing protocol.

Flexural strength

Flexural strength testing followed ASTM C 78 (2002). This is a fundamental material property used in concrete pavement design. Under dynamic loading conditions, cracking occurs when the flexural strength of the material is exceeded due to bending, leading to structural damage and a

Table 2. Results of laboratory unconfined compressive strengths for candidate materials at ambient temperature.

Unconfined Compressive Strength														
Ambient Temperature														
Rapid Set DOT Mix (CTS Cement)			Thoroc 10-61 (Degussa)			Pavemend EX-H (CeraTech)			Aquacrete (Ultimax)			Ultimax Concrete (Ultimax)		
Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)
2	4,180	5,270	4	3,820	3,520	2	60	**Note A**	2	1,430	2,140	2	Too weak	2,140
2	4,660	5,580	4	3,870	3,660	2	**Note A**		2	1,840	1,710	2	Too weak	1,710
2	4,850	5,790	4	3,970	3,690	2			2	1,980	2,230	2	Not cast	2,230
6	7,090	7,430	6	4,060	3,870	6	90	90	4	2,410	2,540	6	2,850	2,350
6	7,390	7,150	6	4,180	3,910	6	90	90	4	2,480	2,520	6	3,900	2,810
6	7,420	7,240	6	4,040	4,050	6	**Note A**	90	4	2,610	2,620	6	4,390	Bad test[B]
24	8,440	8,540	24	4,760	4,700	24	2,660	2,700	24	3,270	3,440	24	7,710	7,980
24	8,700	8,690	24	5,190	4,740	24	2,620	2,560	24	3,070	3,400	24	8,040	7,980
24	8,520	8,790	24	5,260	4,810	24	2,400	2,530	24	3,260	3,390	24	Not cast	7,770
672*	11,070	10,950	672	8,220	7,950	672	4,370	4,380	672	6,640	6,970	672	9,610	10,350
672	10,990	11,420	672	8,190	8,040	672	4,340	4,310	672	6,370	6,730	672	9,900	10,200
672	10,320	not tested	672	8,290	7,850	672	4,400	4,220	672	6,100	7,130	672	Not cast	10,470

* 672 hours = 28 days

Notes:

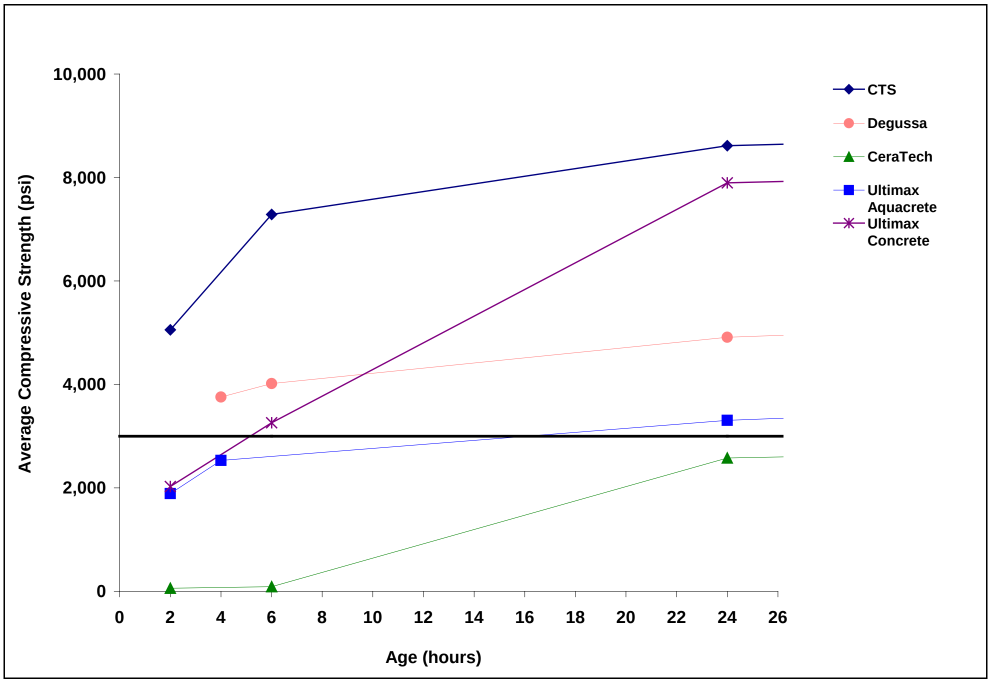
A - Due to initial low compressive strength, test specimens were tested at later ages,

B - Specimen tested at 7-hrs.

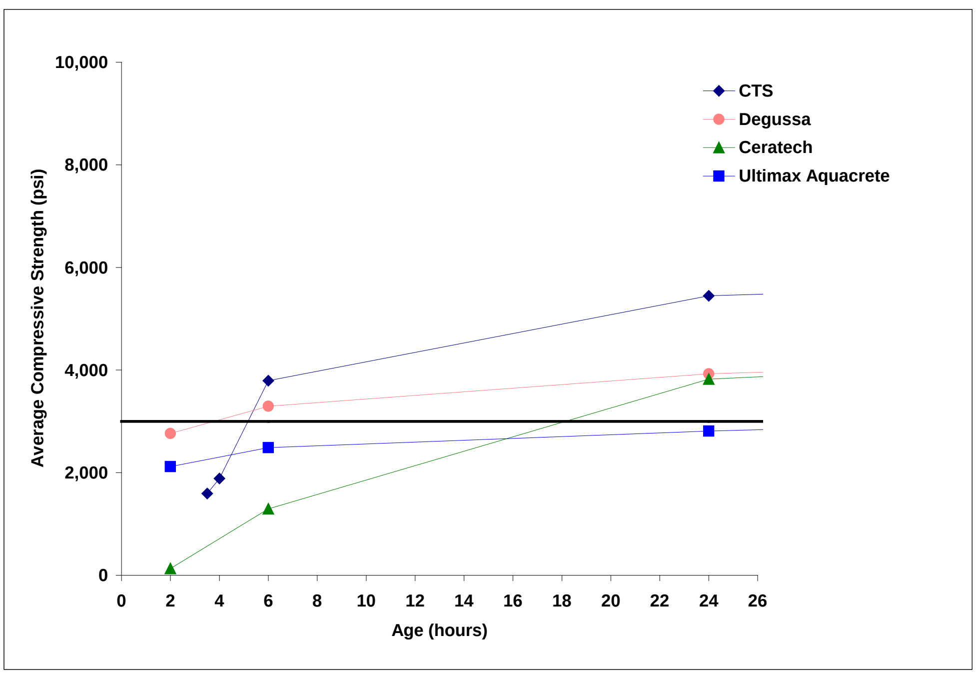
Table 3. Results of laboratory unconfined compressive strengths for candidate materials at elevated temperature.

Unconfined Compressive Strength																	
Elevated Temperature																	
Rapid Set DOT Mix (CTS Cement)				**Thoroc 10-61 (Degussa)**			**Pavemend EX-H (CeraTech)**			**Aquacrete (Ultimax)**			**Ultimax Concrete (Ultimax)**				
Test Time or Age (hours)	Set 1 (lbs/in^2)	Test Time or Age (hours)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)	Test Time or Age (hours)	Set 1 (lbs/in^2)	Set 2 (lbs/in^2)		
4	1,680	3.5	1,370	2	3,680	1,830	2	150	110	2	2,150	1,840	**Not Tested**				
4	2,080	3.5	1,490	2	3,520	1,910	2	150	110	2	2,150	2,190					
4	1,900	3.5	1,920	2	3,630	2,020	2	160	100	2	2,050	2,330					
6	3,470	6	4,140	6	4,260	2,240	6	1,710	570	6	2,460	2,440					
6	3,600	6	4,330	6	4,220	2,320	6	1,920	690	6	2,530	2,500					
6	2,970	6	4,250	6	4,350	2,390	6	1,620	1,250	6	2,510	2,480					
24	5,040	24	5,780	24	5,040	2,700	24	3,830	3,870	24	2,790	2,780					
24	5,170	24	5,860	24	5,120	2,730	24	3,680	3,900	24	2,750	2,750					
24	5,000	24	5,830	24	5,090	2,890	24	3,840	**Not cast**	24	2,820	2,980					
672	7,870	672	8,410	672	8,260	5,090	672	7,950	8,020	672	5,110	4,830					
672	8,120	672	8,500	672	8,230	5,200	672	7,780	7,800	672	5,650	5,330					
672	7,630	672	8,400	672	8,160	4,770	672	8,090	**Not cast**	672	5,040	5,180					

Note: The Ultimax Concrete material was not tested at the elevation condition due to supply and scheduling issues.



a.



b.

Figure 1. Laboratory average unconfined compressive strength values for (a) ambient and (b) elevated temperatures.

shortened pavement service life. Beam specimens were cast in the laboratory and tested at 2 hr, 6 hr, 24 hr, and 28 days. The Ultimax Concrete RS material used a retarder at ambient temperature, and the CTS Cement material used was retarded at both ambient and elevated temperatures. The RS laboratory test results are given in Table 4 and 5 for ambient and elevated temperature testing conditions, respectively. The average flexural strengths are shown in Figure 2 for the ambient temperature condition (a) and the elevated temperature (b) condition. The solid line indicates the recommended value from the spall materials testing protocol.

Bond strength by slant shear

This material property considers the ability of the RS repair material to bond to either ordinary Portland cement (OPC) or to itself. The testing procedures were performed in accordance with ASTM C 882 (2005). In a full-depth slab repair, such as a large crater, this material property may take on more significance where the RS material is placed in multiple, smaller batches. Cylindrical specimens were cast and tested at 24 hr and 28 days. The laboratory test results for both temperature conditions are listed in Table 6.

Modulus of elasticity

Modulus of elasticity testing was conducted per ASTM C 469 (2002), and was tested to determine the rate of modulus gain during a short cure period. Modulus is a material property used in rigid pavement design procedures, and it is best that the modulus of the RS material is not significantly different from the host material. Cylindrical specimens cast in the laboratory were tested at ages of 2 hr, 6 hr, 24 hr, and 28 days. The CTS Cement mixes were retarded at both temperature conditions, while the Ultimax Aquacrete material was retarded at the ambient temperature. The results of the laboratory testing at the ambient and elevated temperature conditions are given in Table 7 and Table 8, respectively, and the average modulus of elasticity values are given in Figure 3. The solid line indicates the recommended value from the spall materials testing protocol.

Table 4. Results of laboratory flexural strength values for candidate materials at ambient temperature.

Flexural Strength Ambient Temperature									
Rapid Set DOT Mix (CTS Cement)		Thoroc 10-61 (Degussa)		Pavemend EX-H (CeraTech)		Aquacrete (Ultimax)		Ultimax Concrete (Ultimax)	
Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2
2	445	4	375	2	**Note A**	2	155	2	155
2	600	4	380	2		2	190	2	190
6	785	6	450	6	**Note B**	6	225	6	225
6	705	6	400	6		6	250	6	250
24	785	24	535	24	105	24	410	24	410
24	845	24	550	24	130	24	445	24	445
672	860	672	740	672	225	672	230	672	230
672	795	672	780	672	310	672	260	672	260

Notes:
A - Specimens broke during handling;
B - Due to initial low strength values, test specimens were tested at later ages,
6-hr test age specimens were tested at 24-hrs, and 24-hr test specimens were tested at 28-days.

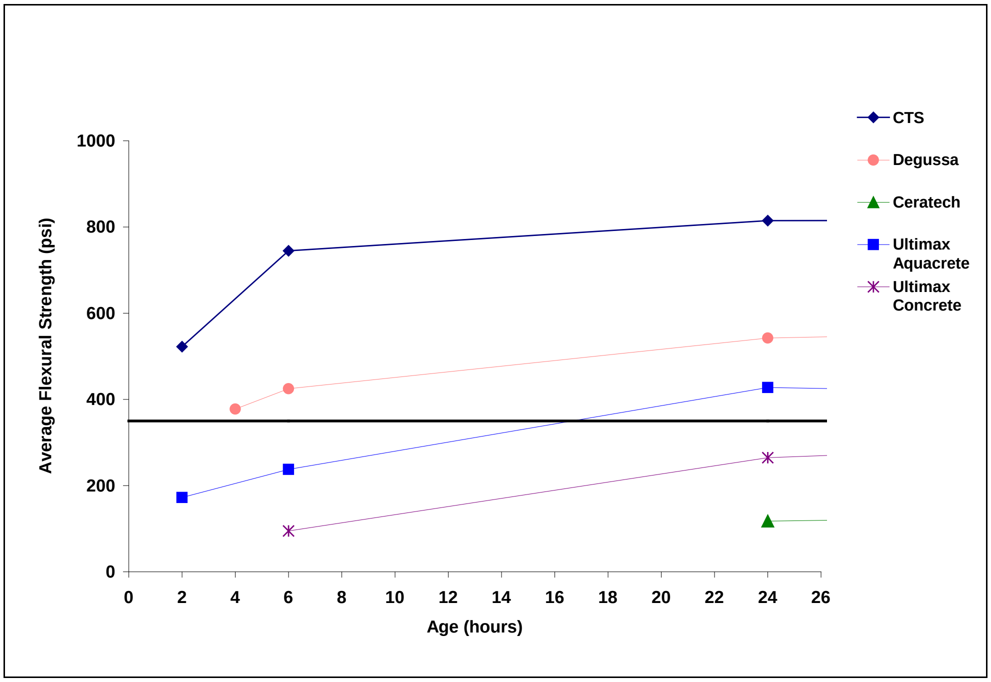
Table 5. Results of laboratory flexural strength values for candidate materials at elevated temperature

Flexural Strength									
Elevated Temperature									
Rapid Set DOT Mix (CTS Cement)		Thoroc 10-61 (Degussa)		Pavemend EX-H (CeraTech)		Aquacrete (Ultimax)		Ultimax Concrete (Ultimax)	
Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2
3	no test	2	240	2	80	2	70	Not Tested	
3	130	2	170	2	85	2	85		
6	525	6	335	6	225	6	205		
6	480	6	355	6	230	6	180		
24	690	24	365	24	350	24	380		
24	655	24	420	24	365	24	330		
672	670	672	545	672	550	672	180		
672	635	672	610	672	560	672	210		

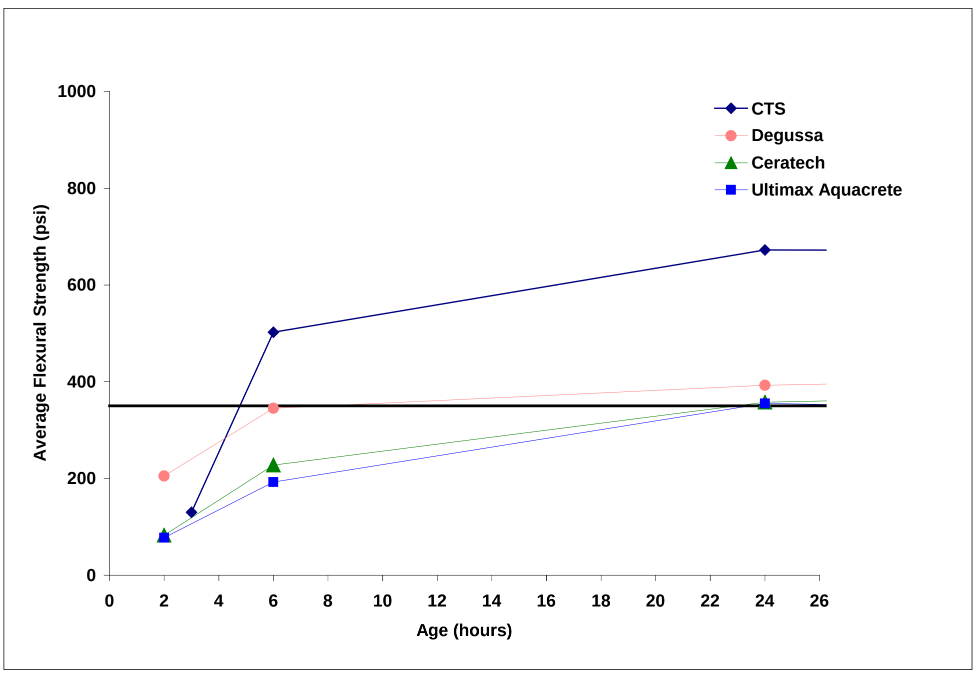
Note: The Ultimax Concrete material was not tested at the elevated temperature condition due to supply and scheduling

Set Time

The set time may be influenced by factors such as the type of cement, water-cement ratio, temperature, and the addition of chemical admixtures (Klieger and Lamond 1994). The test monitors the stiffening of fresh concrete as the hydration process proceeds after the initial contact of water and binder material (Mindess and Young 1981). The designated values of initial and final set are arbitrarily set at 500 and 4,000 psi, respectively. Initial set is considered to be the point at which fresh concrete has lost its workability, and final set is when the concrete begins to gain strength. As applied to RS materials, the set time test indicated how much time was available for placing and finishing the material, how soon the RS materials gain early strength, and when trafficking may begin. Testing was conducted in accordance with ASTM C403 (2005), with some modifications, such as the test was conducted immediately following mixing and used shorter durations between tests to capture when the material set. Figure 4 summarizes the laboratory test results.



a.



b.

Figure 2. Laboratory average flexural strength values for (a) ambient and (b) elevated temperatures.

Table 6. Results of laboratory slant shear bond strength for candidate materials at ambient temperatures.

	Maximum Bond Stress			
	Repair Material to OPC		Repair Material to Repair Material	
Material	1-day (psi)	28-day (psi)	1-day (psi)	28-day (psi)
Rapid Set DOT Cement	1,472	1,136	2,134	2,841
CeraTech Pavemend EX-H	--------	--------	--------	--------
Thoroc 10-61 Repair Mortar	1,236	--------	1,479	--------
Ultimax Aquacrete	--------	--------	--------	--------
Ultimax Concrete	1,047	--------	3,263	--------

Discussion of laboratory results

Effect of temperature

The results from the laboratory testing clearly show the effect of temperature on the RS materials. Between the ambient and elevated temperature conditions, there was a difference of 17 °F. Warmer temperatures significantly reduced the amount of working time, unless a retarding agent was used. As applied to the use of RS materials for large crater repairs, it is highly recommended that testing be completed at both the upper and lower range of expected temperatures, if a considerable temperature range is expected. Likewise, the working time could be improved, if the materials are maintained at cooler temperatures and not allowed to significantly warm up, or if a retarding agent is used following the manufacture's instructions. At a minimum, testing should be conducted at the probable temperature at the time of placement. Based on this, the spall materials testing protocol included provisions for testing materials at the anticipated temperature condition.

Table 7. Laboratory modulus of elasticity values for candidate materials at ambient temperature.

Modulus of Elasticity Ambient Temperature									
Rapid Set DOT Mix (CTS Cement)		**Thoroc 10-61 (Degussa)**		**Pavemend EX-H (CeraTech)**		**Aquacrete (Ultimax)**		**Ultimax Concrete (Ultimax)**	
Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2
2	5.40xE6	4	4.10xE6	2		2	1.10xE6	2	Too weak, not tested
2	5.50xE6	4	4.20xE6	2	**Note A**	2	1.20xE6	2	Too weak, not tested
2	5.65xE6	4	4.20xE6	2		2	1.15xE6	2	Too weak, not tested
6	6.25xE6	6	4.15xE6	6	0.20 x E6	4	1.30xE6	6	2.75xE6
6	6.20xE6	6	4.30xE6	6	0.15 x E6	4	1.30xE6	6	2.65xE6
6	6.45xE6	6	4.45xE6	6	0.10 x E6	4	1.35xE6	7	Bad test
24	7.85xE6	24	4.60xE6	24	2.70 x E6	24	1.60xE6	24	3.80xE6
24	6.70xE6	24	4.75xE6	24	2.65 x E6	24	1.55xE6	24	3.70xE6
24	6.65xE6	24	4.70xE6	24	3.00 x E6	24	1.55xE6	24	3.65xE6
672	6.50xE6	672	5.50xE6	672	3.75 x E6	672	2.30xE6	672	4.45xE6
672	6.95xE6	672	6.70 x E6	672	3.90 x E6	672	2.25xE6	672	4.60xE6
672	not tested	672	5.60 x E6	672	3.75 x E6	672	2.30xE6	672	4.60xE6

* 672 hours = 28 days

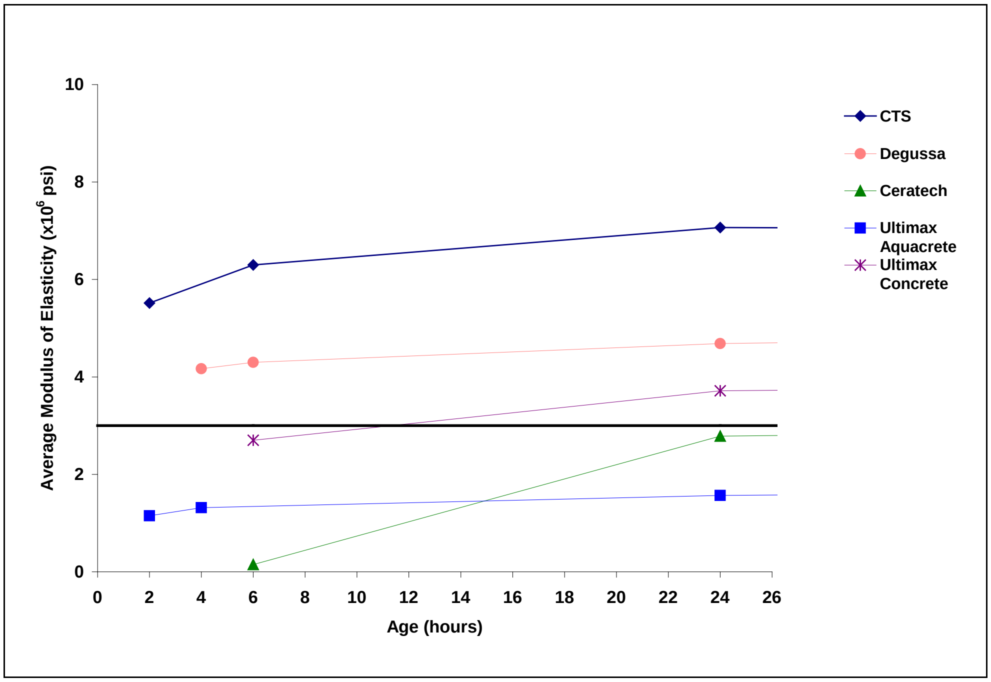
Notes:

A - Due to initial low strength values, test specimens were tested at later ages, for example the 2-hr specimens were tested at 6 hours and the 6-hr specimens were tested at 24-hrs, etc.

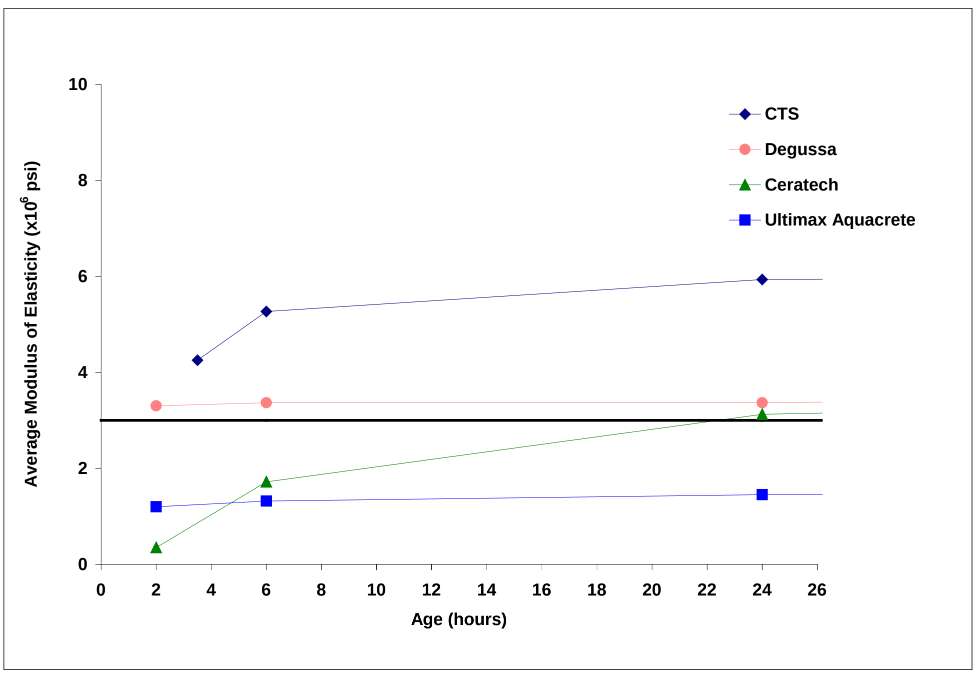
Table 8. Laboratory modulus of elasticity values for candidate materials at elevated temperature.

Modulus of Elasticity									
Elevated Temperature									
Rapid Set DOT Mix (CTS Cement)		Thoroc 10-61 (Degussa)		Pavemend EX-H (CeraTech)		Aquacrete (Ultimax)		Ultimax Concrete (Ultimax)	
Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2	Test Time or Age (hours)	lbs/in^2
3.5	3.85xE6	2	3.00xE6	2	0.40 x E6	2	1.20xE6		
3.5	3.95xE6	2	3.30xE6	2	0.30 x E6	2	1.20xE6		
3.5	4.95xE6	2	3.60xE6	2	0.35 x E6	2	1.20xE6		
6	5.30xE6	6	3.20xE6	6	1.45 x E6	6	1.30xE6		
6	5.15xE6	6	3.45xE6	6	1.50 x E6	6	1.35xE6		
6	5.35xE6	6	3.45xE6	6	2.20 x E6	6	1.30xE6	Not Tested	
24	5.95xE6	24	3.30xE6	24	3.15 x E6	24	1.45xE6		
24	5.95xE6	24	3.30xE6	24	3.10 x E6	24	1.45xE6		
24	5.90xE6	24	3.50xE6	24	Not cast	24	1.45xE6		
672	6.60xE6	672	4.25xE6	672	4.98 x E6	672	2.05xE6		
672	6.35xE6	672	4.40xE6	672	5.20 x E6	672	2.05xE6		
672	6.35xE6	672	4.50xE6	672	Not cast	672	2.00xE6		

Note: The Ultimax Concrete material was not tested at the elevated temperature condition due to supply and scheduling



a.



b.

Figure 3. Laboratory average modulus of elasticity values for (a) ambient and (b) elevated temperatures.

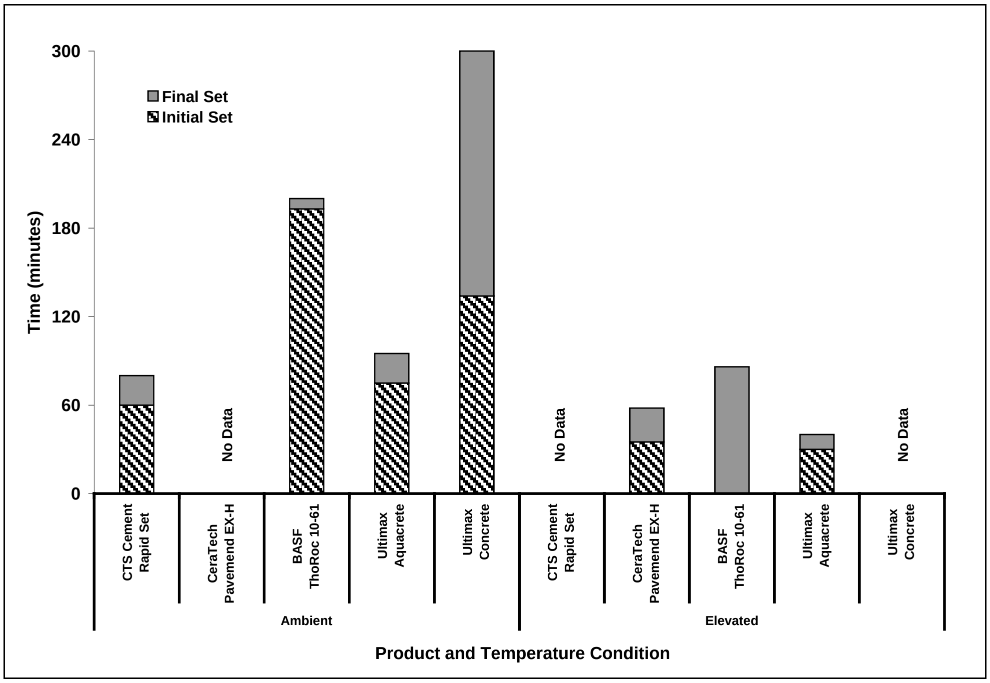


Figure 4. Laboratory set time results for candidate rapid setting materials at ambient and elevated temperatures.

Compressive strength

The materials testing protocol recommends that the compressive strength range reach a minimum of 3,000 psi at 2 hr and 5,000 psi at 24 hr. At the early-age of 2 hr, the laboratory results at ambient air temperature conditions show a wide range of strengths from less than 100 psi (CeraTech) to 5,000 psi (CTS Cement) (Figure 1a). Both of the Ultimax RS materials reached 1,500 and 1,800 psi for the Concrete and Aquacrete materials, respectively; and the Ultimax Concrete material used a retarder. The Degussa product, at a test age of 4 hr, exceeded the 3,000 psi recommendation. The use of a retarder did not appear to affect the strength of the CTS Cement material at ambient temperature. Yet, the CeraTech product required more than 6 hr to gain appreciable strength. Only two products continued to gain strength and exceeded the 5,000 psi limit at 24 hr, CTS Cement and Ultimax Concrete, while the Degussa product just reached the recommended limit. Both the CeraTech and Ultimax Aquacrete products were well below the 5,000 psi target at 24 hr.

At the elevated temperature condition (Figure 1b), none of the RS materials tested reached a minimum 3,000 psi at a test age of 2 hr. Only the CTS Cement material reached the 5,000 psi target at 24 hr.

Flexural strength

As shown in Figure 2a, the test results for flexural strength indicate that the CTS Cement RS material clearly exceeded the recommended 350 psi at 2 hr. At a test age of 4 hr, the Degussa product reached the recommended value. Neither of the Ultimax products met the requirement at the 2 hr test age. At this early age, the CeraTech specimens broke during handling, and only reached 100 psi at the 24 hr test age. At 24 hr, both the Degussa and Ultimax Aquacrete materials exceeded the 350 psi criteria. At the elevated temperature condition (Figure 2b), none of the RS materials obtained a strength of 350 psi at 2 hr. However, all of the materials did just reach the 350 psi target at 24 hr, with the CTS Cement product exceeding 600 psi.

While flexural strength was a material property evaluated by Vaysburd et al. (1999), the investigation found no relationship between the flexural strength and field performance of the materials. Additionally, ACI (American Concrete Institute) reported that the flexural strength of a material is typically not a property that limits a material's performance (ACI 2006).

Bond strength by slant shear

Table 6 lists the test results for the bond strength by slant shear for the repair material cast to OPC and the material cast to itself. Based on the limited test data, all of the test materials exceeded the recommended strength of 850 psi at the test age of 24 hr for repair material cast to OPC, and 1,000 psi for the repair material cast to repair material.

Modulus of elasticity

In general, the test specimens showed the greatest gain in modulus value within the initial 24 hrs. At the ambient temperature condition, the CTS Cement product well exceeded the protocol recommendation of 3×10^6 psi at 2 hr and 4×10^6 psi at 24 hr. At 4 hr, the Degussa product reached 4×10^6 psi, exceeding the recommended criteria. The Ultimax Concrete product exceeded the recommended criteria at a test age of 24 hr. While the CeraTech product neared the target at 24 hr. The Ultimax Aquacrete product did not reach the recommended criteria at either test age. At the elevated temperature condition, the Degussa product met the 2 hr criteria, but did not reach the 24 hr target. The CTS Cement material exceeded the criteria at 3 hr. The CeraTech product reached the target at 24 hr.

Set time

The set time test gave an indication on how much time was available for placing and finishing the material, and how soon afterward the RS materials may gain early strength. RS materials that set too quickly do not provide enough working time to place and finish the material, resulting in a rough surface. Conversely, RS materials requiring too much time to reach final set may delay re-opening the airfield for operations.

At ambient temperature, the Rapid Set DOT Cement reached final set in the shortest amount of time at 80 min followed by the Ultimax Aquacrete at 95 min. Both the ThoRoc 10-61 and Ultimax Concrete materials required more than 3 hr to reach final set. Testing at an age of 4 hr translates into the material having a very early age strength. It should be noted that a retarding agent was included in the mixes for the Rapid Set DOT Cement, Ultimax Aquacrete, and Ultimax Concrete materials. Also, additional water was needed when mixing the Rapid Set DOT Cement, ThoRoc 10-61, and Ultimax Concrete Aquacrete materials. The amount of time elapsed for the mixture to reach final set from the onset of initial set ranged from as rapidly as 7 min (ThoRoc 10-61) to 20 min (Rapid Set DOT Cement and Ultimax Concrete Aquacrete). The Ultimax Concrete material needed almost 3 hr to reach final set once the onset of initial set began. No data is available for the Pavemend EX-H material at ambient temperature.

Both the ThoRoc 10-61 and Ultimax Aquacrete materials show a marked decrease in the set time at the higher temperature condition. The time at which final set at the elevated temperature, 20 °C higher, was reached was reduced by 57 percent. While it is unclear when initial set occurred for the ThoRoc 10-61 material, final set did occur 2 hrs earlier at the elevated temperature for ThoRoc 10-61 and 1 hr earlier (faster) for Ultimax Aquacrete, as compared to the ambient temperature condition.

Based on the laboratory results, it is recommended that set time testing should be included in the materials test protocol. It seems reasonable to propose that the RS material provides roughly 60 min of working time before reaching initial set. Less time, such as 30 min, would also be satisfactory, and would allow the material additional time to gain strength after reaching final set. Final set should be reached as soon as practical after initial set. Times longer than 90 minutes may not allow adequate time for strength development.

Summary of laboratory testing

The spall materials testing protocol provided good/valuable/effective guidance on material properties that are germane to a large crater, or full-depth slab repair, application. While some of the materials testing was incomplete due to time constraints, the laboratory phase offered familiarization with the RS materials under controlled conditions. The materials tested in this study are a small sampling of the numerous products available. For this reason, it is difficult to generalize the performance of these broad types of RS materials. It is recommended that untried RS materials should be tested continually to build a materials database.

There was a significant difference in the material properties at the elevated temperature condition. It is recommended that laboratory testing should be conducted at the anticipated usage temperature.

Despite the fact that early-age testing at 2 hr, for all of the test material properties, was not always feasible, in some cases due to the set time, this early test age provided a good stringent guide that separated the materials. This is a critical early-age test.

Based on the results of the laboratory testing, the materials that most consistently showed the best performance, compared to the protocol at the early-age 2 hr tests, were the RS products from CTS Cement and Degussa. The Ultimax Concrete, Ultimax Aquacrete, and CeraTech RS products met the later-age 24 hr criteria only for limited criteria. Nevertheless, the performance of all of these RS materials will be tested during the full-scale field trial.

4 Field Test Site

Test site description

Full-scale field testing was conducted in June 2006 at the Silver Flag training site located at Tyndall Air Force Base, FL. The test area was located on the southern end of the training runway. The existing runway consisted of ordinary Portland cement (OPC) and was crowned for drainage. Figure 5 shows the test area and identifies the location of one of the repair craters, Crater 2, on the left side of the runway centerline.

Figure 5. Photograph of test area at the Silver Flag Exercise Site taken during the initial field site visit.

The layout of the crater repair locations within the test area is shown in Figure 6. As they were simulated craters, the repair locations were constructed by removing the existing material (multiple slabs) and preparing the subsurface - no explosives were used to create crater positions. At the location of Crater 4, the thickness of four recently replaced slabs was less than the existing pavement. The two small circular objects at the location of Crater 2 (Figure 6) were small craters removed for the test. The circular object on the northern end beyond the test area, was a large static crater, at least 30 ft in diameter, which remained unchanged. The red lines

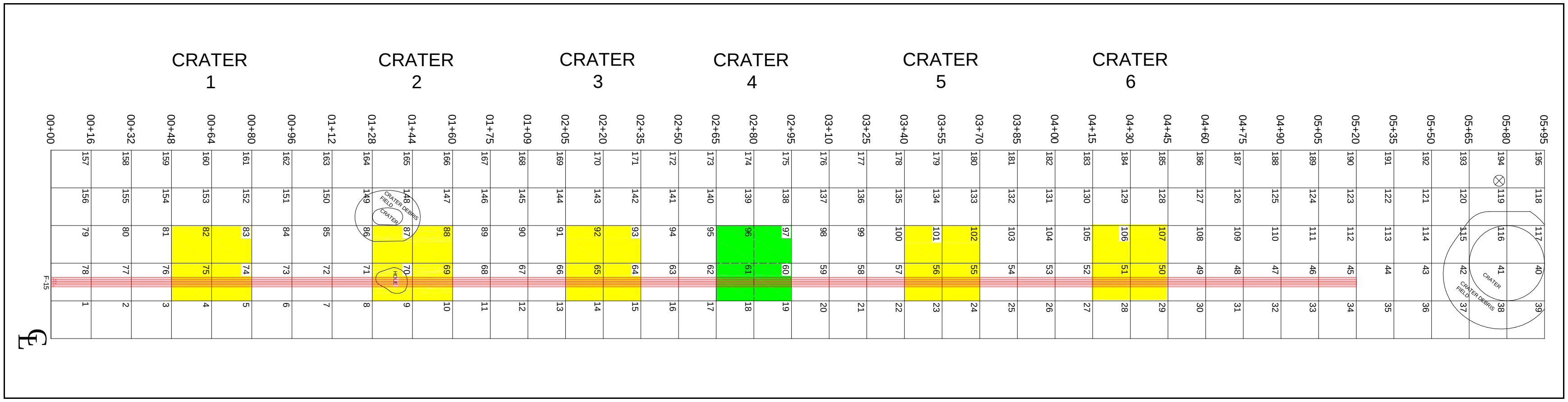
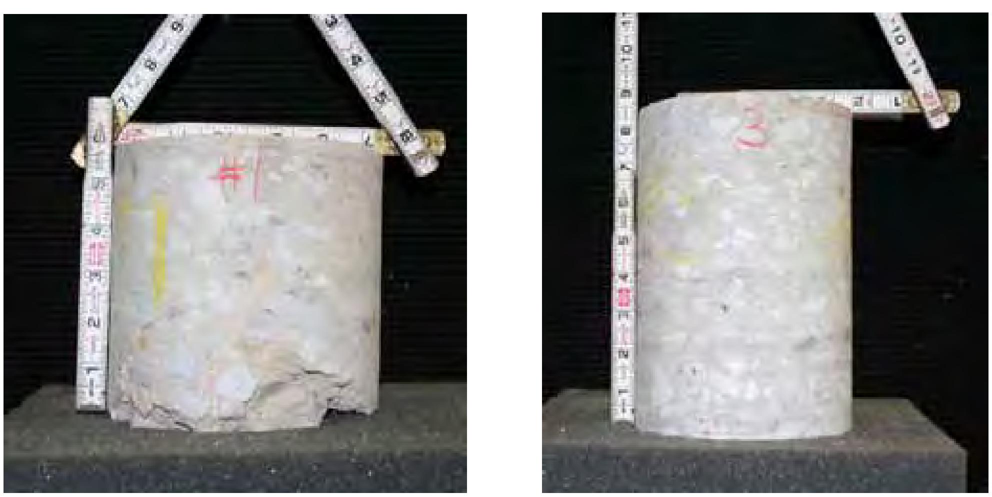


Figure 6. Layout of test area indicting locations of each simulated test crater and load cart trafficking lanes.

in Figure 6 indicate the traffic lane for the load cart. The traffic lane consisted of 5 lanes, each 9 in wide, for a 45 in simulated wander width. The traffic lane was offset approximately one-third of the width of the test crater to traffic away from the center of the repair and capture any edge effects.

The size of the individual slabs, four of which were removed, for Craters 1 and 2 were 16 ft by 15 ft, slightly larger than the slabs removed for the other four craters, which were 15 ft x 15 ft. A slab thickness of 8 in yielded a total repair volume of 24 yd^3 for Craters 1 and 2. Craters 3 through 6 were 30 ft by 30 ft, yielding a slightly smaller repair volume of 23 yd^3. To provide enough room to maneuver the load cart, a separation distance of 45 ft (or three slab lengths) was left between Craters 1 and 2, and 30 ft (or 2 slab lengths) was left between Craters 3 and 4.

Prior to any construction activities, non-destructive testing (NDT) with a heavy weight deflectometer was performed and core specimens were coll-ected to confirm that the structural capacity of the test area was adequate. A total of 6 core specimens were collected, two cores retrieved from the vicinity of Crater 4 (Figure 7a) showed thicknesses of 5-3/4 in and 6-1/2 in and consisted of a different material than the surrounding host pavement. These materials were from prior runway repairs. The remaining 4 core samples were collected from the host pavement and ranged in thickness from 7-3/4 in to 8-1/2 in (Figure 7b).



a. b.

Figure 7. Core specimens collected during the structural evaluation (February 2006) taken from (a) the recent repair (Crater 4 location), and (b) slabs in the vicinity of Craters 5 and 6.

The cores were tested to determine the tensile strength following ASTM C 496 (2002), *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, to estimate the flexural strength of the existing pavement. The estimated flexural strengths from the 4 cores coll-ected in the host pavement ranged from 529 to 621 psi, with an average of 577 psi.

Soil samples were collected from the core holes for grain size analysis. Soil samples collected from the 2 core holes in the recent repair (Crater 4) classified the base course material at a 6-1/2 in depth as being a sandy silty gravel, and at an 8-1/2 in depth as a sandy gravel. Based on the soil sam-ples collected from the remaining 4 core holes, there is approximately 3 in of a sandy silty gravel base course material below the pavement overlying a poorly graded silty sand subgrade. All of the base and subgrade materials were non-plastic.The structural evaluation determined that the Silver Flag location was suitable for testing. Given this assessment, it was important that the thickness of the repaired craters not exceed the thickness of the existing pavement, to prevent failure of the host slabs before crater repairs. To minimize any impacts from the load cart and reduce the overall number of slabs to be replaced at the end of the testing, AM2 matting was placed in limited locations at both ends of the traffic lane, between Craters 1 and 2, and between Craters 5 and 6 prior to crater repairs (Figure 8).

Figure 8. Placing AM2 matting in traffic area to protect existing pavement.

Preparation of test craters

To prepare the simulated craters for this study, the existing pavement was broken out and removed using a pavement breaker and a backhoe (Figure 9a and 9b), standard construction equipment.

a. pavement breaker

b. backhoe

c. removal of pavement material

d. place the fill material

e. compact the fill material with a vibratory roller (not pictured) and vibratory plate compactors

f. apply water to the test sections to prevent the fill material from drying out from the hot weather and continuous sun exposure

Figure 9. Preparation of the test craters showing the techniques and equipment used to break out and remove existing pavement.

Clean, vertical faces were maintained by breaking the pavement out along the existing joints during the removal, without the need to saw cut. Several dowel rods were encountered on the upper west edge of Crater 3 and were cut back flush. No other dowels were encountered in any of the other crater locations. The broken concrete was removed using a multi-terrain loader (Figure 9c).

Once the pavement was removed, a layer of fill material (crushed concrete, available on site) was placed and compacted to approximately 8 in below the surface of the existing pavement. The fill material was spread with a multi-terrain loader, wet, and compacted with a vibratory drum roller in the center of the test crater, and with vibratory plate compactors along the edges (Figure 9d to Figure 9f). The gradation of the fill material is given in Figure 10. Efforts were made to prepare each crater as consistently as possible to allow fair comparison of the performance of the RS material. Once the test craters were prepared, the base layer in each crater was surveyed to determine the cap layer profile. The nominal thicknesses of the cap layer for each test crater are listed in Table 9.

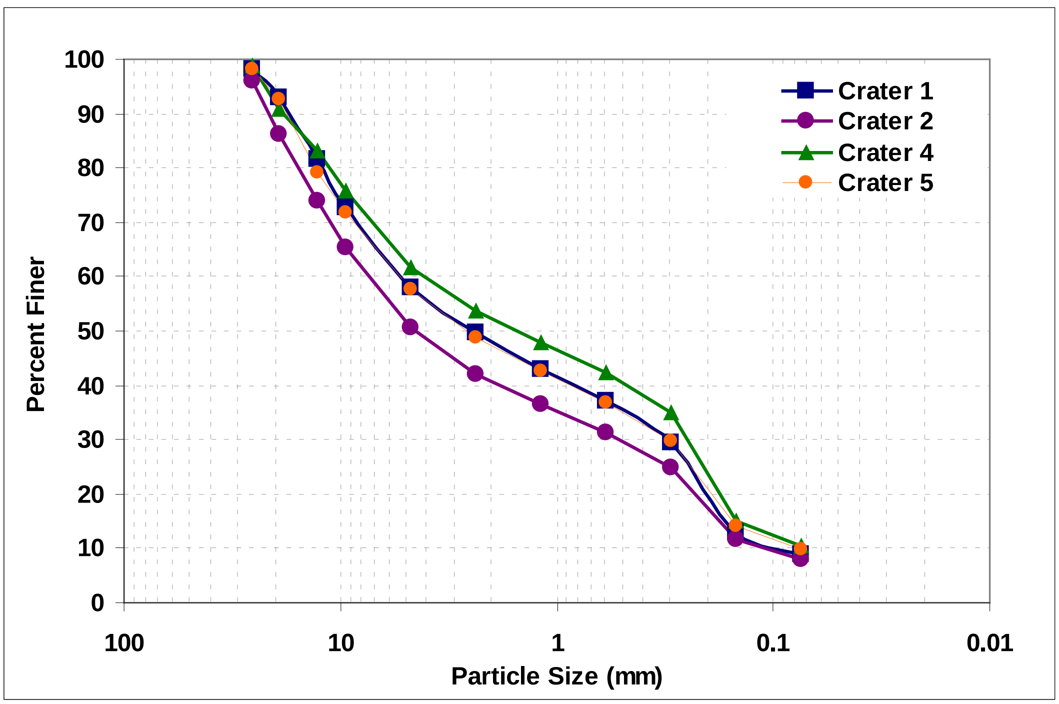


Figure 10. Grain size distribution of crushed pavement fill material used during preparation of the test craters.

Table 9. Thickness of cap layer.

	Nominal Cap Layer Thickness (in.)
Crater 1	8.26
Crater 2	9.05
Crater 3	[a]
Crater 4	8.11
Crater 5	8.39
Crater 6	8.68
[a] Incomplete repair, see Crater 3 Repair section.	

Instrumentation

Instrumentation was installed in the test craters at locations shown in Figure 11. Pressure cells and moisture sensors were installed in the base layer, and temperature sensors were installed in the cap to measure the heat of hydration during curing. For consistency, the instruments were installed at similar depths and locations in each test crater. Two pressure cells were installed in the traffic lane, at 1 ft and 7-1/2 ft from the south edge of each test crater. Figure 11 illustrates both the plan and profile views of the sensor locations in Craters 5 and 6. This same layout was used in all of the test craters. Two sets of each type of instrument were installed to take readings at different locations in the test crater and also to act as a backup in the event that one sensor failed.

The lead wires connecting the instrumentation to the data collection systems were buried in a shallow trench along the edge of each test crater, where possible. Otherwise, the wires were buried in a shallow trench crossing the test crater and painted to identify their position to safeguard the wires from potential damage(Figure 12). The wires exited the test crater through a piece of conduit in the corner. On the pavement surface, the wires were protected between 2 in by 4 in pieces of lumber nailed into the pavement (Figure 13). All of the earth pressure cells were connected to a Campbell Scientific CR5000 datalogger (Figure 14a). The temperature, moisture, and weather station instruments were wired to a Campbell Scientific CR10X datalogger (Figure 14b).

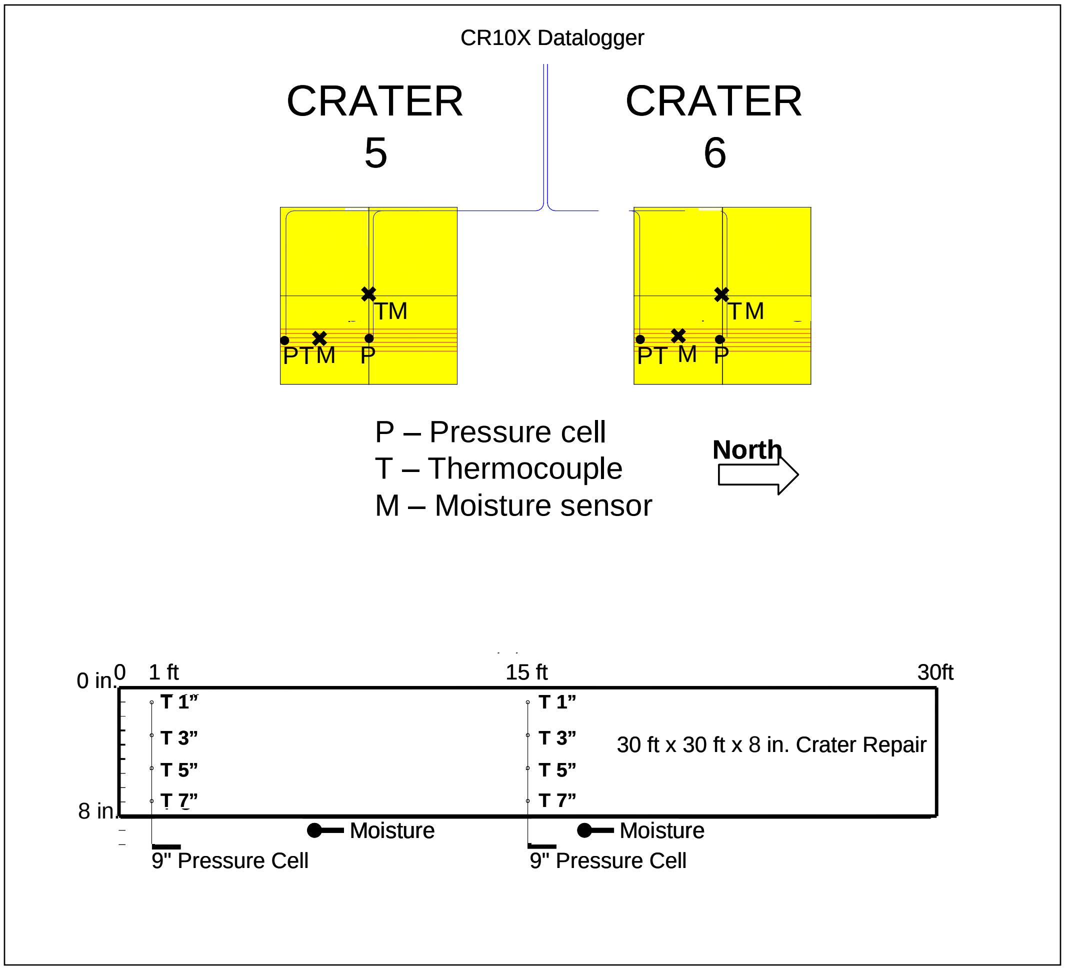


Figure 11. Plan (a) and profile (b) views of the instrumentation locations in the test craters.

Figure 12. Installed instrumentation in test crater.

Figure 13. Photograph showing protected instrumentation wires routed to data acquisition system off the runway edge.

a. CR5000

b. CR10X

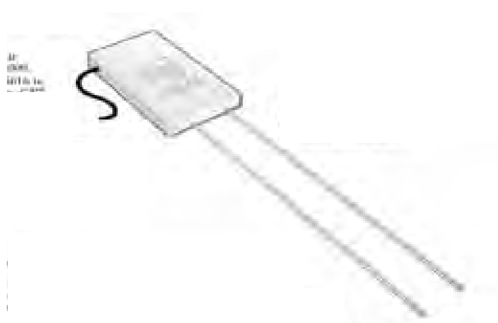
Figure 14. Data collection systems used.

Earth pressure cells

Geokon, Inc. Earth Pressure Cells, Model 4800, were used to measure both the dynamic pressure readings of the rolling F-15E load cart tire, and the static readings of the pavement overburden pressure. The pressure cells consisted of two 9 in diameter, circular stainless steel plates with a thin, hydraulic-fluid filled gap sandwiched in between (Figure 15a).

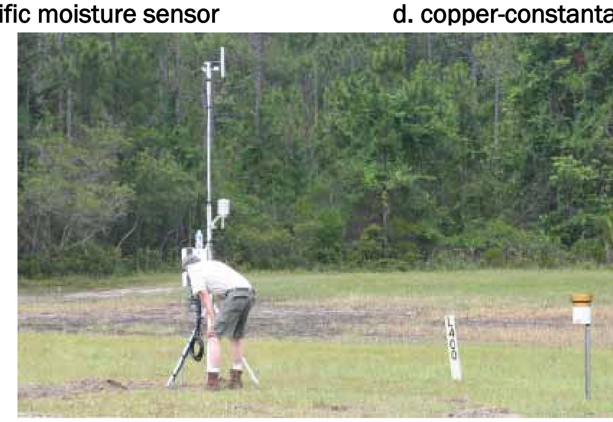
a. Geokon Earth Pressure Cell

b. Geokon pressure cell installed in Crater



c. Campbell Scientific moisture sensor

d. copper-constantan thermocouple string



e. weather station with windset and rain gage (mounted on post, right side of photo)

Figure 15. Instrumentation installed in the test craters.

When pressure was applied, the plates were forced toward each other and displaced the internal fluid. This displacement was translated into a signal output from a pressure transducer (Geokon, Inc. 2002). This sensor is capable of pressure readings up to 50 psi (0.35 MPa).

The pressure cells were installed just below the surface of the fill material. During the installation, the pressure cells were leveled and the material used to backfill over the pressure cells was free from any large stones. To accomplish this, the cell was embedded in a thin layer of sand to both cushion the cell and provide good contact. Figure 15b shows a pressure cell installed in the sand layer.

Moisture sensors

Campbell Scientific CS616 water content reflectometers were installed just below the surface of the fill material. The sensors were installed to monitor any changes in the moisture content of the fill layer. Two sensors were installed in each test crater, one in the southeastern corner, and the other in the center of the test crater. The principle operation of the sensor uses reflectometry associated with the dielectric properties of the surrounding material to measure the volumetric moisture content. The dielectric value of water is much greater than either that of soil or air; therefore, the moisture content of the soil surrounding the probe influences the frequency of the signal. The probe consists of two stainless steel metal rods that are approximately 11 in long and connected to a circuit board (Campbell Scientific 2004, Figure 15c). The time required for a signal transmitted down the length of the rod to be reflected back is influenced by the moisture content of the material. Higher moisture contents reduce the velocity of the reflected signal. A general calibration curve is used to convert the voltage output into a volumetric soil moisture content value.

According to the manufacturer's documentation, the accuracy of the device is ±2.5% volumetric water content when the general calibration equation is used. The accuracy of the probe is influenced by proper installation. If not installed properly, the accuracy of the moisture measurement may be reduced due to air gaps between the rods and the material. Uniform spacing between the parallel rods must be maintained, as a bent rod or an uneven space will impact measurements.

Temperature sensors

Thermocouples were used to record the temperature history in each test crater. They consisted of 20-gage high-quality, type T, copper-constantan wire. The operation principle of thermocouples is that two wires of dissimilar metals are joined to create a path over which an electromagnetic force flows. There are two junctions, one at the measurement tip where the two metals are in contact with each other, and the other is where the wires are connected to the datalogger. A temperature change between the two junctions results in a change in the output voltage. A reference temperature is required to detect the change in voltage and convert it to a corresponding temperature.

Among the advantages of using thermocouples for measuring the temperature are that they provide a wide operating temperature range, they are accurate within ±0.5 °F, they are inexpensive, they are easy to install, and are durable. Disadvantages of thermocouples include the need for a reference temperature, as it is important that the reference temperature remain stable.

Four thermocouples were spaced 2 in apart and attached to a dowel rod at 1, 3, 5, and 7 in to produce a thermocouple string (Figure 15d). This 2 in spacing allowed the temperature to be monitored 1 in below the surface of the cap material, 1 in above the bottom of the RS cap layer, and at two depths through the middle of the cap material. Two thermocouple strings were installed in each test crater, one in the center and one in the southeastern corner, for a total of eight temperature readings per test crater. The lead wires were connected to a Campbell Scientific CR10X data logger (Figure 14b).

To install a thermocouple string, the dowel rod was hammered into the fill material. The dowel rod was of sufficient length to remain vertical once installed. Since the thermocouples are above the surface of the fill layer, they are susceptible to damage, particularly during placement of the RS cap material.

Weather station

In addition to the sensors installed in the test craters, meteorological data was collected to monitor the conditions at the test site. Measurements for air temperature, relative humidity, precipitation, wind speed, and wind

direction were recorded during the testing period. Figure 15e shows the weather station set up at the site.

Soil strength and density

Following the placement and compaction of the backfill material, soil strength and density verification measurements were conducted in each crater. Plate bearing tests were conducted to determine the modulus of soil reaction, or k-value. Measurements made with the dynamic cone penetrometer (DCP) provided a profile of the soil strength with depth. Soil density measurements were made with a Troxler nuclear density gauge, Model 3440.

Plate bearing testing was conducted in accordance with CRD-C 655-95 (U.S. Army Corps of Engineers 1995) in the northeast corner of each test crater by the AFCESA team. The purpose of the test was to determine the modulus of subgrade reaction, or k-value, which is the ratio of the applied load to the volume of displacement. The test was conducted approximately 3 ft from either edge of the existing pavement (Figure 16a and b).

a. setting and leveling the plates b. a test in progress

Figure 16. Plate bearing testing on the crater base course material.

A bulldozer provided the reaction force. The maximum contact pressure of 30 psi was reached in all of the craters, with the exception of Crater 3 where a maximum contact pressure of 25 psi was recorded. The k-values were consistently measured as 250 or 275 lb/in^3, as listed in Table 10, indicating a high material strength.

In each test crater, DCP tests were performed in the northern and southern sections and in the center (Figure 17). The average CBR values were determined and then converted into a k-value. The estimated k-values

Table 10. Soil strength and density values in the base course material from the plate bearing and DCP.

	Plate Bearing	DCP
	Corrected k-value (lb/in^3)	Averaged CBR (%)
Crater 1	275	30
Crater 2	250	30
Crater 3	275	25
Crater 4	250	> 30
Crater 5	275	25
Crater 6	250	25


Figure 17. Soil strength testing with the DCP.

from the DCP compare well with the plate bearing test at 250 for a CBR of 25, and 300 for a CBR of 30, in accordance with pavement evaluation criteria (AFCESA 2002).

Density and moisture content measurements of the base layer were conducted using a Model 3440 Troxler nuclear gauge (Figure 18) in accordance with ASTM D 2922 (2004) and ASTM D 3017 (2004). The Troxler gauge contains Cesium-137, a radioactive element. In the direct transmission mode, the source rod with the radioactive element is extended 6 in into the soil. When the gauge is activated, gamma photons are emitted from the source rod through the material and sensed by gamma detectors in the base of the unit (Troxler 2003). The wet density measurement is the

Figure 18. Soil density measurements with the Troxler nuclear gage.

average of the depth between the base of the unit and the depth of the extended source rod. Two sets of readings were taken at each of three locations per test crater. After the first reading, the gauge was turned 90 degrees and a second set of readings was taken.

The average dry density and moisture content values for each test crater are listed in Table 11. The dry density and moisture content of the test craters averaged 120 lb/ft^3 and 11%, respectively. The in situ density and

Table 11. Average nuclear gauge dry density and moisture content values for test craters.

	Average	South	Center	North
Crater 1	Dry density (lb/ft^3)	122	124	117
	Moisture content (%)	11	10	11
Crater 2	Dry density (lb/ft^3)	118	120	120
	Moisture content (%)	10	10	12
Crater 3	Dry density (lb/ft^3)	119	122	122
	Moisture content (%)	10	12	10
Crater 4	Dry density (lb/ft^3)	121	121	115
	Moisture content (%)	11	12	14
Crater 5	Dry density (lb/ft^3)	122	122	120
	Moisture content (%)	12	11	11
Crater 6	Dry density (lb/ft^3)	119	122	122
	Moisture content (%)	12	12	12

moisture readings were relatively consistent between test craters allowing for meaningful comparisons between the materials used for the cap layer. The prepared simulated craters, prior to the repairs, are shown in Figure 19 through Figure 24.

Figure 19. Crater 1 prior to cap placement.

Figure 20. Crater 2 prior to cap placement.

Figure 21. Crater 3 prior to cap placement.

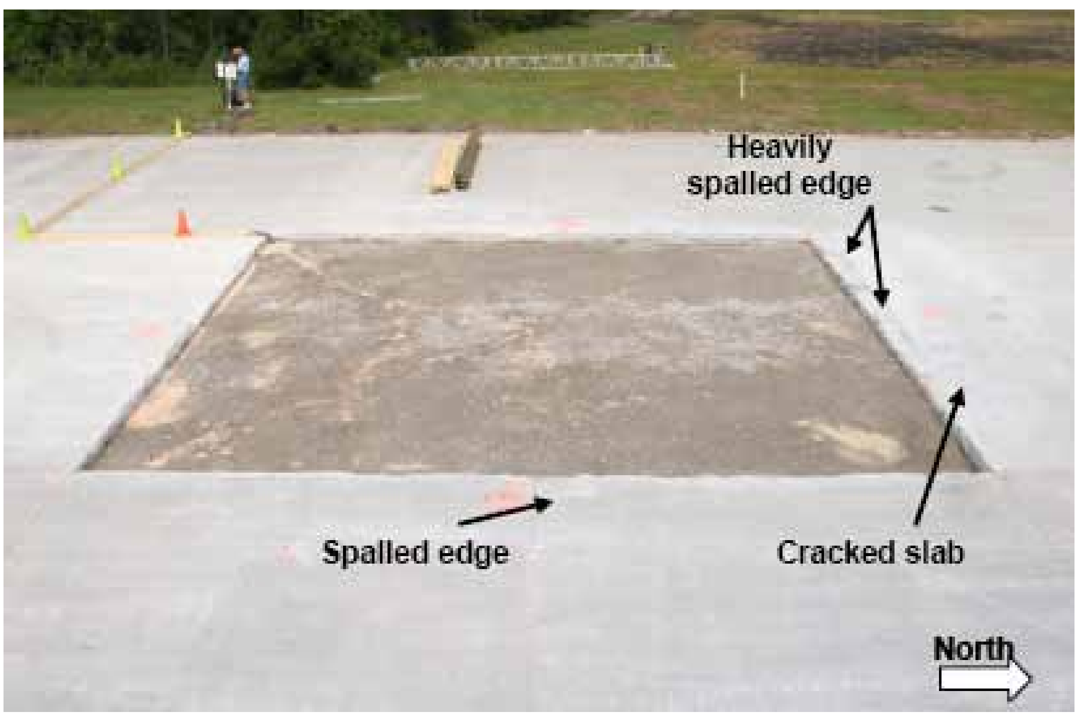


Figure 22. Crater 4 prior to cap placement.

Figure 23. Crater 5 prior to cap placement.

Figure 24. Crater 6 prior to cap placement.

Equipment and material storage

Construction equipment

The equipment used both to prepare the craters for repair and to conduct the repairs consisted of standard heavy construction equipment rented from a local equipment company (Table 12).

Table 12. List of equipment used for crater repairs.

Quantity	
2	5 yd^3 dump truck
2	Tracked multi-terrain loader
1	Fork attachments
	Bucket attachment
1	Sweeper
2	Vibratory plate compactors
1	Backhoe with bucket
1	Backhoe with hydraulic pavement breaker
1	Extending forklift, 10,000 lb capacity
1	Vibratory compactor, smooth drum
1	Truss screed, 40 ft
2	Portable concrete mixers, 9 ft^3
1	Water truck, 2,000 gal
1	Front end loader, 3 yd^3
1	Concrete vibrator, 2HP 12-ft shaft
2	Concrete saw

Mixing equipment

This study considered a suboptimal scenario where a standard size ready-mix truck would not be available to conduct the repairs. This situation would be representative of a typical expedient repair scenario where all equipment and materials must be transported via air to the site. Instead, the materials were mixed in a sideloading, portable, concrete mixer with a capacity of 2 yd^3. The mixer was a commercially available Porta Mix Model 202, manufactured in Spring, TX. This was the smallest size mixer considered for this project, and given the capacity of this mixer, multiple batches of material were required to fill the cap volume.

This gas powered mixer was 17 ft long, 7 ft high, and mounted on a trailer for towing with a full-size pickup truck (Figure 25a). A metal grate, with 1 in-size openings, covered the top of the mixing drum and obstructed

access into the mixer drum (Figure 25a). Difficulties with the grate opening size appeared after several days of continuous usage when the openings became clogged with hardened cement. At the rear of the mixer was a stowable, sliding 2 ft chute. Figure 25b shows the paddle configuration. Because the mixer was delivered to the field site the day before the first repair was scheduled, it was tested with only water and aggregate to familiarize the field crew with its operation.

a. mixer showing tow bar b. configuration of paddles

Figure 25. Portable concrete mixer, 2 yd^3 capacity, used for crater repairs.

To supplement the 2 ft chute on the portable mixer for placing material at the interior of the crater, a 16 ft aluminum concrete chute was used with the mixer. It turned out that the length of the chute was cumbersome to move around, difficult to attach, and the metal supports across the top made it difficult to use hand shovels to move the material down the length of the chute (Figure 26).

Figure 26. Concrete chute.

To monitor the amount of water added to each mix, a water meter was installed on the water truck (Figure 27).

Figure 27. Water meter.

Aggregates for extending

For RS material vendors wishing to extend the RS material used in the repair, aggregate was available on site. The grain size distribution for each material is shown in Figure 28.

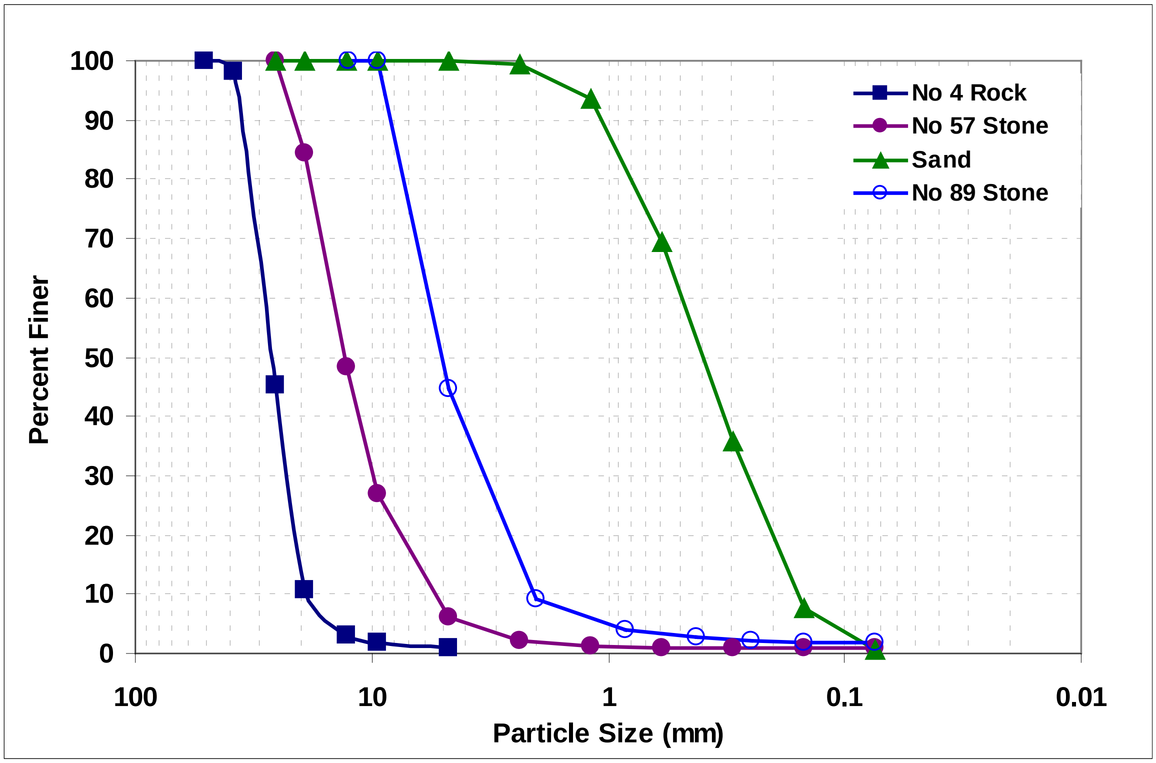


Figure 28. Particle size distribution of materials available on site.

The No. 4 rock (maximum 2 in) was the material gradation used for the stone-grout control crater. The No. 57 stone (maximum 1-1/2 in.) was the material gradation intended to be the primary aggregate to extend with the rapid setting cap materials. However, it became clear that the stone size was too large for the paddles in the portable mixer, and a smaller aggregate size would be required. Therefore, the No. 89 stone (maximum ½ in) was the material gradation that worked in the portable mixer and was used to extend the majority of the cap materials.

RS materials

The RS materials were shipped in large supersacks ranging from 2,000 to 3,000-lbs each. Once offloaded from the trucks, the RS materials were stored under tents in the staging area to protect them from the elements (Figure 29).

Figure 29. Tents used in the staging are where rapid setting cap materials were stored.

5 Large-Scale Field Testing–Crater Repairs

Introduction

In all, six crater repairs were conducted with each allotted a full day for completion. The schedule and RS material manufacturer are listed in Table 13. The craters were not repaired in numerical order, and in this section, they will be presented in the order in which they were repaired. The first crater repair – Crater 1 – that used the stone and grout was intentionally scheduled for the first day to familiarize the airmen and soldiers with the mixing equipment, the material, and to establish a mixing sequence. While the grout was an accelerated mix, the set time was not as rapid as the other RS materials. The crater repair that used the Degussa product required 2 days to complete. This was the first commercial RS material used in the portable mixer extended with the #57 coarse aggregate. At the very beginning of the repair for Crater 5, the shaft stopped turning when the stone became wedged between the paddles and the side of the mixer. This issue was resolved by acquiring smaller diameter coarse aggregate and the repair was completed the following day.

Table 13. Crater repair schedule.

	Repair Date	Material
Crater 1	June 20	Stone and grout (Control)
Crater 2	June 27	CeraTech, Pavement EX-H
Crater 3	June 29	Ultimax, Aquacrete
Crater 4	June 28	Ultimax, Concrete
Crater 5	June 23 and 24	Degussa, ThoRoc 10-61
Crater 6	June 22	CTS, Rapid Set DOT mix

The crater repairs were labor intensive. The team that performed the repairs to Craters 1, 5, and 6 was composed of 9 airmen and 7 soldiers. For Craters 2, 3, and 4, twelve airmen conducted the repairs.

Crater 1 repair – stone and grout (control section)

Crater 1 was the control section repaired using the stone and grout method following current guidance in *UFC 3-270-07, O&M: Airfield Damage Repair* (2002). The stone and grout method is considered suitable for a

sustainment repair for runways (U.S. Army Corps of Engineers 2002), and is designed to withstand 5,000 passes of the mission aircraft. As specified, the stone and grout repair consists of a 16 in layer of stone and grout material overlying a 12 in layer of crushed stone with a minimum CBR of 25 percent. At the Silver Flag Exercise site, the stone and grout layer was 8 in thick and placed over the layer of fill material. The crushed stone base layer was not included as the DCP measurements presented in Table 10 show CBR values of 25 percent and higher for the backfill material placed in each crater.

The procedure to complete the stone and grout repair followed UFC 3-270-07 (2002). The grout mix design consisted of 24 sacks of Type I cement, 33 lb of Calcium chloride (accelerator), 6.5 lb of friction reducer (Daxad-19), and 1,005 lb of water (120 gal) per 1 yd^3. Prior to placing the grout into the crater, a layer of polyethylene was placed over the base material. A layer of sand, approximately 12 in wide and 1 to 2 in deep, was placed along the inside edge of the crater to prevent grout from seeping under the existing slabs. A thin layer of the 4 in stone was then spread over the plastic.

The weather conditions during the morning of the repair were sunny, hot, and humid. The temperature of the pavement was noted at 109 °F. The morning of the repair, a test batch of grout was mixed in the portable mixer. The mixer had just been delivered the previous day and an initial test run only used water. A ½ yd^3 of the mortar was mixed and placed in the northeastern corner of the test crater. An attempt to mix a full yard of mortar in the mixer resulted in unsatisfactory mixing and the material was discarded. This was followed by an engine hydraulic leak caused by a broken O-ring, requiring repair before continuing.

Since a mix size of only ½ yd^3 was successfully mixed in the portable mixer, this batch size was selected and used for the remaining mixes to complete the repair. At 1300 hr, the mixer was positioned at the northeastern corner of the crater and another ½ yd^3 test batch was mixed (Figure 30). This mixture showed good consistency and the repair continued with ½ yd^3 mixes produced in only 4 minutes. Prior to adding material to the mixer, the paddles were rotating. The sequence of materials added to the mixer for a half-cubic yard was:

Figure 30. Crater 1 repair resumed following repair of hydraulic leak.

- Fill two 5 gal buckets with 4 gal of water each and set aside;
- Divide the dry friction reducer (Daxad-19) and mix ½ each into the 5 gal buckets;
- Fill two additional 5 gal buckets with 5 gal of water each and set aside;
- Add 30 gal of water into the mixer chamber;
- Add 6 sacks of cement (individual 94-lb bags) into the mixer;
- Add one of the buckets with friction reducer to the mixer;
- Add the remaining 6 sacks of cement into the mixer;
- Add the remaining mix water (20 gal);
- Divide the calcium chloride and mix into the two 5 gal buckets of plain water to put the mixture into solution before adding it to the mixer. This mixture heats up quickly with temperatures reaching or exceeding 140 °F.
- Add the 2^{nd} bucket of friction reducer to the mixer;
- Add the Calcium chloride mixture as the last component;
- Continue mixing until the material is blended and uniform (approximately 30 seconds or less) and discharge;
- Repeat the sequence by immediately adding the mix water for the next batch. This mixing sequence goes rapidly. It's best to have a 2^{nd} set of four 5 gal buckets available to batch and mix both the friction reducer and calcium chloride to have them ready for the next batch.

At the start of a batch, several observations became clear regarding the portable mixer and the work area. At the start of a batch, some of the mix

water would leak out the rear discharge gate, even while water was being added into the chamber. Once the cement had been added and sufficiently mixed no additional water was lost. Any lost mix water was collected and returned into the mixer (Figure 30). The working platform around the mixer was narrow; for that reason, a forklift was used to lift pallets of cement and assist in the transfer of the bagged cement into the mixer.

Mixing in small half-yard batches continued until the grout filled to the top of the 4 in stone layer. The mixer was then repositioned to the south end of the crater, and mixing and filling the crater continued. The freshly placed grout was spread using concrete rakes. Additional stone was added in the northeastern corner with the front-end loader (Figure 31). The stone was vibrated into the grout using vibratory plate compactors (Figure 32). Care was taken to not add too much aggregate to the grout (Figure 33). Excess aggregate inhibits a sufficient grout coating around the aggregate, resulting in a somewhat 'dry' consistency. Grout splattering as the vibratory plate passed indicated the addition of sufficient stone. After vibrating with the plate compactors, a multi-terrain loader with a bucket attachment was used to back-blade and level the surface of the stone. The stone and grout layer was brought to within ¾ in below the surface of the existing pavement. The final layer consisted of grout only and was placed to bring the repair flush to the height of the existing pavement.

Figure 31. Adding stone to grout layer in Crater 1.

Figure 32. Vibratory plate compactors used to vibrate stone into grout mixture in Crater 1.

Figure 33. Adequate coating of grout around stone in Crater 1.

Approximately 1 hr and 10 min after resuming the repair, the water truck left to refill the tank. While the water truck was away, the mixer was repositioned at the northwestern corner of the crater. Additional stone was added with the multi-terrain loader, was spread with concrete rakes, and

was vibrated in using the plate compactors. Mixing resumed 15 min later using the same sequence of steps as before. Roughly 20 min later, the mixer pulled away from the crater to try to clean out some of the grout buildup before continuing with the repair. During this time, the effort continued to fill low areas. Aggregate was spread, leveled, and vibrated into the grout. When the mixer returned, it was positioned on the north side of the crater to begin flooding the top layer with grout.

After two hours of continuous mixing for the crater repair, the openings of the metal grate on the top of the mixer became clogged. Additional effort was required to distribute the cement into the mixer to maintain the mixing tempo. Evenly distributing cement between the center and both ends of the mixer helped to keep material flowing into the mixer.

When the mixer was repositioned a second time at the south end of the crater, a truss screed was moved into place on the eastern edge (Figure 34). Once the mixer was repositioned to the west side of Crater 1, screeding began as the surface of the grout was beginning to stiffen (Figure 35). On the west side of the crater, grout flooding continued, and then the mixer was backed further into the crater to flood the center.

Figure 34. Setting up truss screed on east side of Crater 1.

Figure 35. Crater 1, screeding the repair.

Roughly four hours and forty-five minutes after resuming the repair, a magnesium bull float was used to finish the surface. Hand floats were also used to finish around the crater edges. Grout was poured into 5 gal buckets and used to fill in any low areas. Shrinkage cracks were forming on the eastern side of the repair. The completed repair was covered with a sheet of plastic to aid curing. After restarting the repair following the mixer maintenance delay, the repair was completed in 5 hr and 54 min.

Moisture accumulated on the underside of the plastic cover indicating good curing. The following morning, after the plastic sheet was removed, extensive shrinkage cracks covered the surface of the repair (Figure 36), particularly in the low areas that had been filled with grout. To insure that the existing pavement would not be adversely affected, the repair was saw cut into four quadrants (Figure 37). The surface of the repair was re-wet and recovered with the plastic sheet to continue curing until testing.

In all, 25 half-yard batches were mixed to complete this repair. The total time required was approximately 12 hr, to include the time needed for both the team to become familiar with the mixer and to repair the hydraulic leak. The actual time required to complete the repair was 5 hrs and 54 minutes.

Figure 36. Shrinkage cracks in the surface of the stone and grout repair, Crater 1.

Figure 37. Saw cutting joints in Crater 1 stone and grout repair.

Temperature readings

Temperatures at the center of the repair (Figure 38) reached a maximum of 137 °F at sensor depths of 1 and 3 in. The maximum reading at the 5 in depth was 133 °F. The temperature sensors at the corner location showed higher temperature readings than the center location. In the corner, the upper two sensors at 1 and 3 in below the surface reached temperatures of 158 and 160 °F, respectively, approximately 8 hr after the repair was resumed (Figure 39). The 5 in sensor lagged and reached a maximum temperature of 147 °F 9.5 hr after the repair continued. The maximum temperature 7 in below the surface was lower, and likely due to the sensor being located in the stone layer.

Moisture readings

The volumetric moisture readings in the base layer of Crater 1 remained steady throughout the entire testing period (Figure 40).

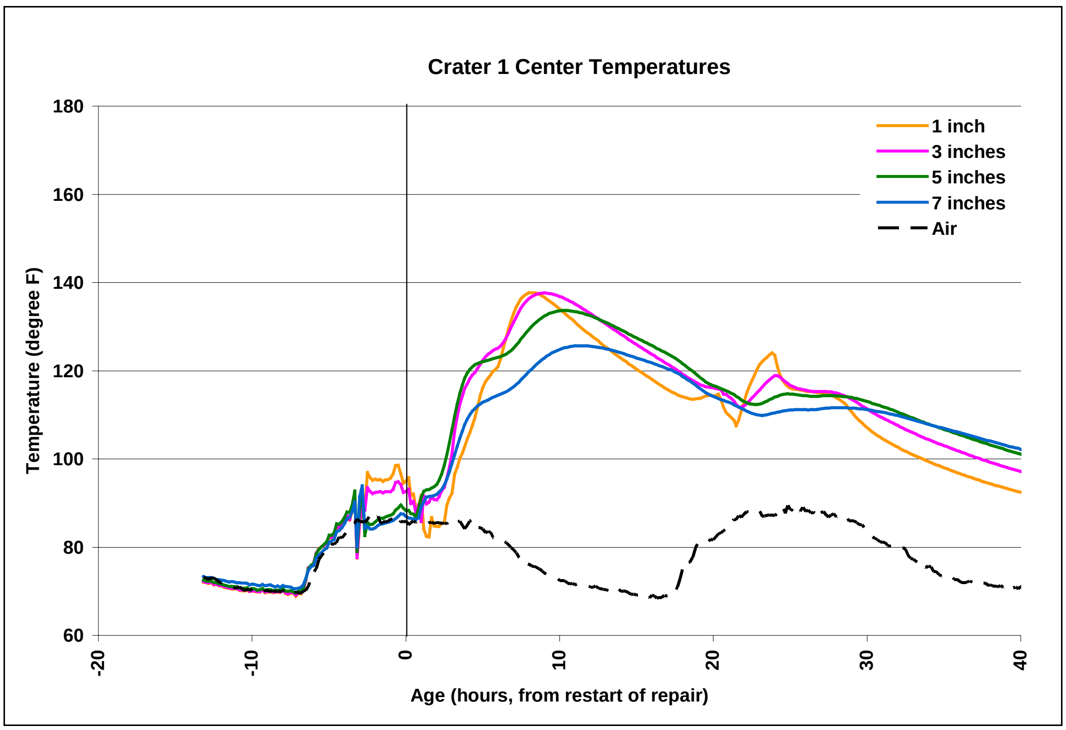


Figure 38. Temperatures in center of Crater 1 stone and grout repair.

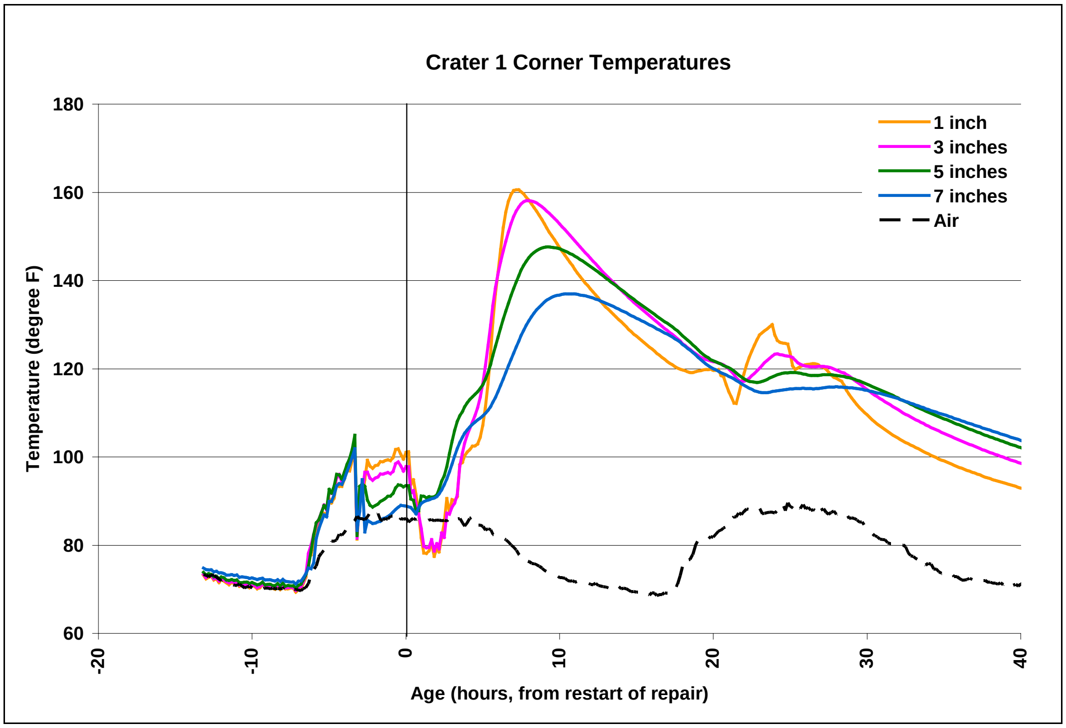


Figure 39. Temperatures in southeastern corner of Crater 1 stone and grout repair.

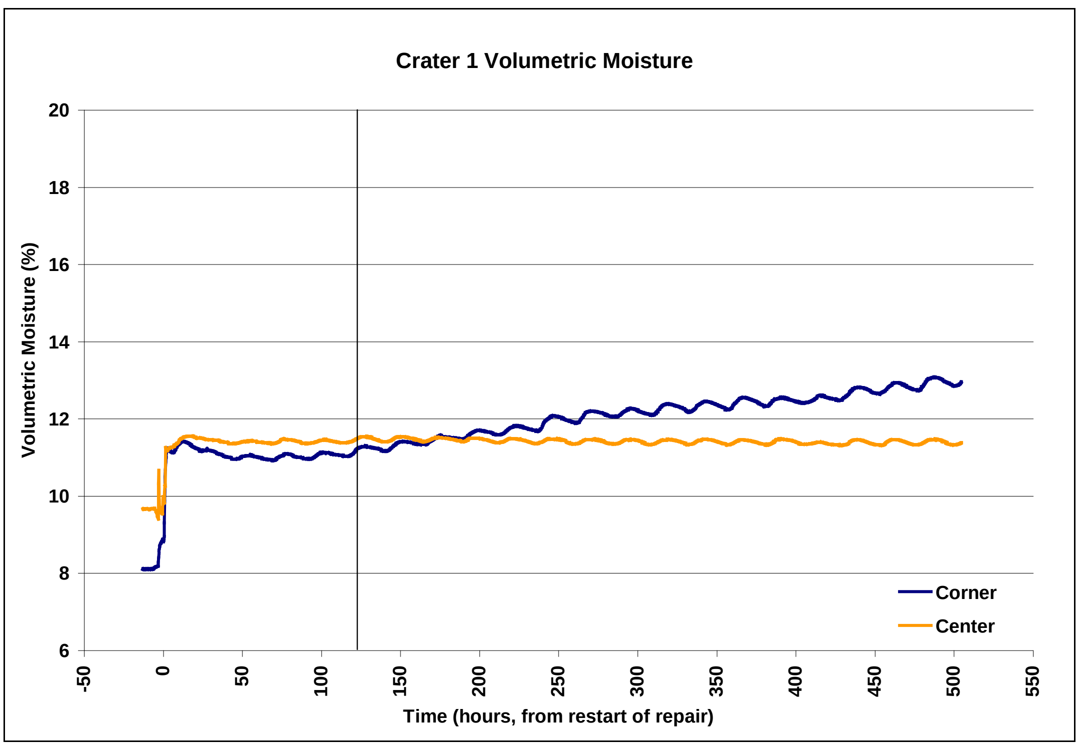


Figure 40. Crater 1 moisture sensor readings in the base layer throughout the testing period.

Crater 6 Repair – CTS Cement, Rapid Set DOT Cement

The repair for test Crater 6 was the second repair conducted during the full-scale field testing. This was the first crater repair performed using commercial RS material. However, instead of using the portable mixer, this repair was completed using a volumetric mixer provided by the vendor. As previously mentioned, the vendors were permitted to use specialized equipment if they believed it would produce a better repair, provided the vendor would make the arrangements to have the equipment arrive on site. The mixer was a 6 yd^3 proportional mixer manufactured by Zimmerman Industries (Ephrata, PA). It should be noted that the size of the mixer used for this field trial would not be transportable on a C-130 aircraft. Conversely, Zimmerman does manufacture a smaller proportional mixer of a size conducive for transport by a C-130 aircraft. Two representatives from Zimmerman, along with the owner of the truck calibrated and operated the machine during the repair. With regard to the amount of material needed, 10 supersacks, each weighing 2,000 lb, of DOT cement were delivered on site.

The afternoon prior to the repair, the machine was calibrated for the specific mix design (Figure 41). The mix called for 600 lb of cement, and was extended with sand and No. 57 stone. The calibration procedure

Figure 41. Calibrating the proportional mixer for Crater 6.

involved determining the correct rate that each material is dispensed into the mixing auger. During the calibration, the individual materials were processed through the volumetric mixer, collected into a container, and weighed. The final mix design for a 3,500 psi mix called for 600 lb of DOT cement, 1,218 lb of sand, 1,820 lb of No. 57 stone, and 32 gal of water. Citric acid, a retarding agent, was added at a rate of 3 gal per yd^3 to the mix water to extend the working time. Total time to calibrate the machine was approximately 3 hr.

The crater was divided into quadrants using forms made of 2 in x 10 in pieces of lumber, cut to length. The forms were held in place with metal stakes (pieces of steel rebar) and fastened together at the corners with screws (Figure 42). Using the forms replaces the need for saw cutting since the hardened concrete will crack along the cold joint.

Figure 42. Formwork prepared for Crater 6.

The crater repair began at 0900 hr when the sand, stone, and RS material were loaded into the volumetric mixer (Figure 43). As the quantity of materials was depleted, the mixer returned to the stockpiles to be refilled. Moreover, the mixing operation may be uninterrupted by continuously loading the mixer.

Figure 43. Filling the proportional mixer with Rapid Set DOT cement for Crater 6.

The repair sequence was to complete the southwestern quadrant followed by the northeastern quadrant. Once those two sections had set, the forms were removed and the final quadrants were poured. At 1033 hrs, the mixer was positioned at the southwestern quadrant and 10 min later, the RS mix was placed (Figure 44). Concrete rakes were used to spread the material in the quadrant and the material was vibrated with a shaft vibrator. As material was placed beyond the quadrant's halfway point, the finishing operation began by screeding the surface with a scrap piece of lumber (2 in x 4 in) and finishing the surface with a bull float (Figure 45). The surface was hand finished and a broom texture applied to the surface (1117 hr). Additional materials were readied in the truck. At 1158 hrs, the RS material placement began in the northeastern quadrant and was completed by 1220 hrs. The surface of the northeast section was finished similarly to the southwestern section. Both sections were water cured (Figure 46, note that the southwest section has already reached initial set).

The repair resumed at approximately 1300 hr with the removal of the forms. Figure 47 shows a profile view of one of the sides. At 1335 hr, the

Figure 44. Pouring Rapid Set DOT concrete into the southwestern quadrant of Crater 6.

Figure 45. The surface of Crater 6 was screeded and finished.

Figure 46. Water was applied to southwestern section, to aid curing, after completion of northeastern section of Crater 6.

Figure 47. Profile of slab edge of Crater 6 after removal of the form.

RS material was poured into the northwest quadrant and this section was finished by about 1400 hrs. Again, the truck was refilled (Figure 48) and the final quadrant was completed before 1500 hrs. The final repair is shown in Figure 49 as it was trafficked with the load cart.

Figure 48. Refilling proportional mixer with stone and cement for Crater 6.

Figure 49. Crater 6, completed repair surface during trafficking.

Temperature readings

The thermocouple string located in the center of the crater was positioned in the southwestern quadrant and was covered in RS material during the first placement (Figure 50). The thermocouple string in the southeastern corner was in the final quadrant to be poured. The temperature readings of both strings were consistent and more representative of a monolithic placement, reaching a maximum temperature of 126 °F approximately 2-½ hr at the center at the 1, 3, and 5 in depths, and 3-1/2 hr at the corner after placement at depths of 3 and 5 in (Figure 51).

Moisture readings

The moisture sensor readings at the center of Crater 6 (Figure 52) indicate an increase in the moisture content of the base approximately 40 hr after the pour and then again 360 hr after the start of the pour. The increases in moisture content do coincide with rain events, according to the rain gauge. It seems plausible that water infiltrated into the base material through the cold joint in the center of the repair following rain events that occurred well after the repair was completed (during the performance testing period). Based on the response from the corner sensor, located roughly the center of the southeastern section, the readings remained steady through-out the entire testing period.

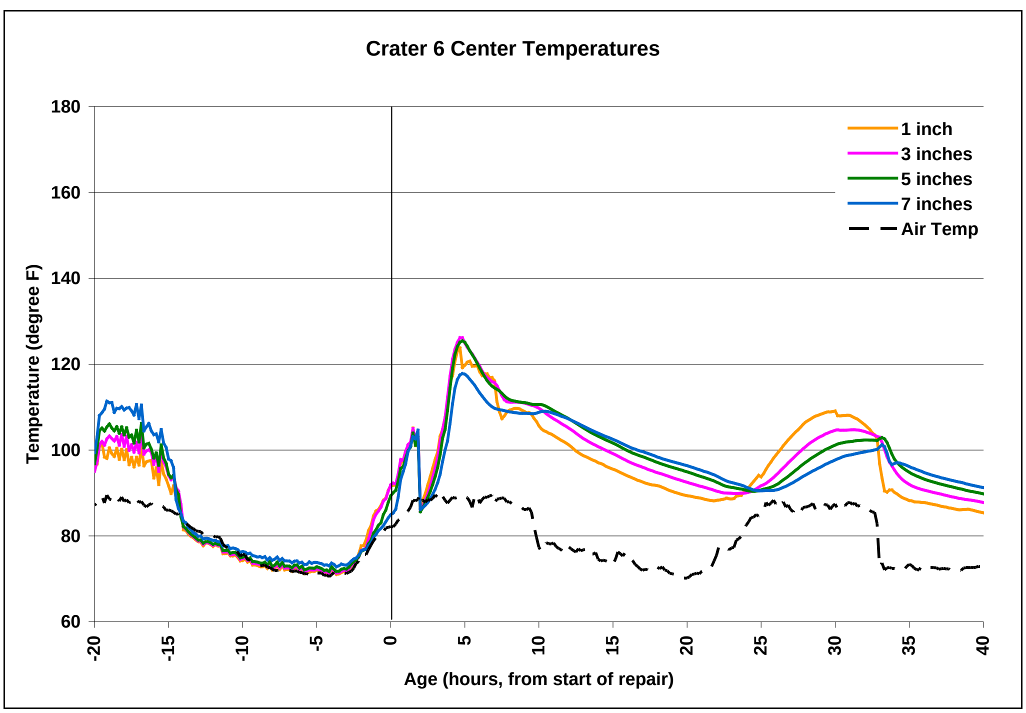


Figure 50. Crater 6 center temperatures.

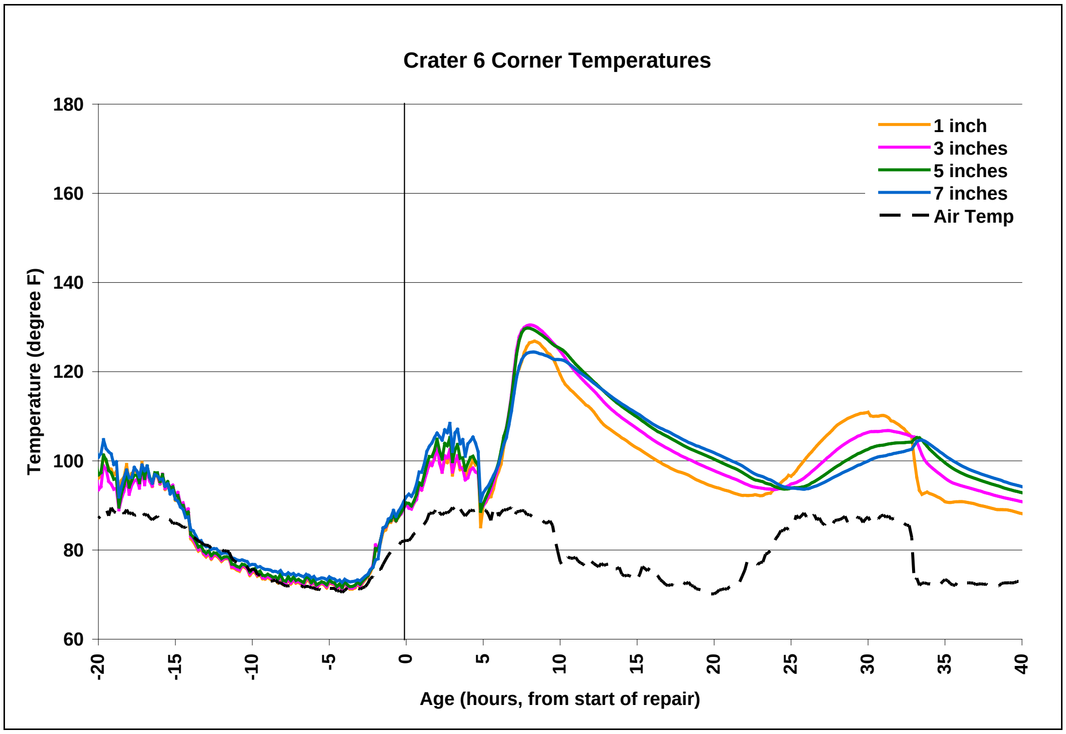


Figure 51. Crater 6 corner temperatures.

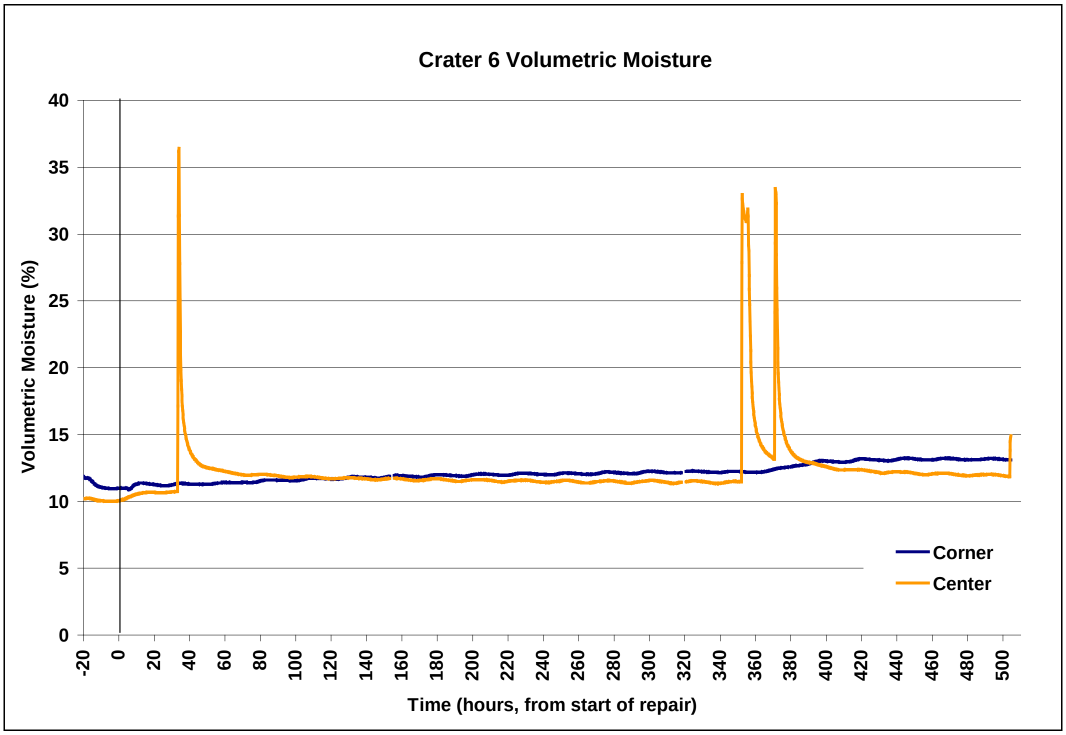


Figure 52. Moisture readings in base layer of Crater 6.

Crater 5 repair–Degussa Building Products, Thoroc 10-61 Repair Mortar

The repair conducted in Crater 5 was the first repair attempted that used the 2 yd^3 mixer to mix and place RS material. The material was ThoRoc 10-61 Repair Mortar, by Degussa Building Products (currently owned by BASF). This material was selected for use by the vendor as it is formulated for conditions where the ambient temperature is above 85 °F, and provides an extended working time (BASF Technical Sheet). The material was shipped to the test site in supersacks, each weighing 2,500 lbs. The material is also available in 50 lb bags, and a pallet containing the smaller sacks was also shipped to the test site in the event that additional material was needed.

Two mixes were designed for this repair crater to adjust for the capacity of the mixer. The first mix design consisted of 34 to 41 gal of water and 1,625 lbs of #57 stone per supersack of the rapid repair mortar. The anticipated yield per supersack was 1.20 yd^3, requiring 21 batches of material to be prepared. The only change to the second mix was that the quantity of the #57 stone was increased to 1,875 lbs, thereby increasing the yield slightly to 1.24 yd^3, requiring only 20 batches of material to be mixed and placed. Both an evaporation reducer and curing compound were applied following the finishing of the RS material.

Forms, made of 2 in x 10 in lumber, were positioned, dividing the test crater into quadrants, and set to grade (Figure 53). Final preparations, that required approximately 45 min, were made before the start of the

Figure 53. Formwork configuration in Crater 5.

repair that included: applying a release agent (food-grade vegetable oil) to the forms with a large paint brush, readying the evaporation reducer and curing compounds into handheld pump spray canisters, and moistening the base material with water.

Two handheld, pump spray canisters were used to apply the evaporation reducer and the curing compound. The evaporation reducer, Confilm (MasterBuilders Technologies), is a liquid in a 1 gal container (Figure 54) that was diluted with water following the instructions on the product label.

Figure 54. Evaporation reducer used for Crater 5 repair.

The mixture was poured into a pump handle spray canister and shaken well to blend. Between applications, the evaporation reducer needed to be agitated to stay blended. It was applied evenly to the surface of the RS material after the surface was finished. A 2-part curing compound, Kure-N-Seal W (Sonneborn) combined with a Kure-N-Seal white color additive, was applied over the evaporation reducer (Figure 55). The label on the curing compound describes the product as, “a transparent acrylic water-based curing, sealing, and dustproofing compound.” Care should be used with the curing compound, as it tends to thicken and clog the nozzle.

Figure 55. Preparation of curing compound used on Crater 5.

At 0750 hrs on the morning of the repair, the mixer was positioned on the southeastern side of the crater, as shown in Figure 53. The water and #57 aggregate (1,620 lbs) were both added into the mixer, with some of the mix water flowing out through the mixer's back gate. The mixer was overloaded and the paddles stopped turning. A second attempt was made to load the mixer and ended with a similar result. The aggregate was wedged between the mixer paddle and interior wall of the mixer. The repair was suspended until a smaller size stone was obtained. A successful test batch using #89 stone with the rapid setting mortar was mixed.

The repair resumed the following morning at 0800 hrs. The mixer was positioned at the northwest quadrant (Figure 56). To accommodate the smaller size of the #89 stone, the quantity of stone was reduced to 1,400 lb per supersack. The quantity of mix water remained the same at a total of 40 gal. To start, while the paddles were turning, an initial 15 gal of water and the #89 stone were metered into the mixer. The remaining 10 gal of water was split into two 5 gal buckets. The batching sequence for the mix was adding 1 supersack of RS material to the mixer (this required 8 to 10 min), add 5 gal of water, mix for 1 min. Add the 2^{nd} 5 gal of water. A rubber mallet was used to strike the bottom of the supersack to keep the material flowing (Figure 57). The batch was mixed for a total of 3 min, which began when all of the RS material was added to the mixer. This first mix appeared somewhat dry, and an additional 4 gal of water was added. The mix was then discharged into the northwest quadrant.

Figure 56. Mixing first batch for Crater 5 repair.

Figure 57. Striking the bottom of the supersack with a rubber mallet to improve material flow for Crater 5.

A full quadrant is too large of a volume to fill without dividing the quadrant into smaller sections. Initially, a temporary form board was held in place until the material set, then the board would be repositioned and the process repeated (Figure 58). However, this proved to be impractical, as

the temporary board was awkward to hold in place at grade level, without securing it, and contributed to an uneven final surface. The second batch filled the section and the surface was screeded with a scrap piece of lumber (2 in x 4 in), vibrated, and finished with a bull float. Several minutes after applying the evaporation reducer and curing compound, shrinkage cracks formed (Figure 59).

Figure 58. Holding the temporary formboard in place in Crater 5.

Figure 59. Shrinkage cracks formed in the repaired northwestern quadrant of Crater 5.

While this first section was being finished, water and stone were added to the mixer for the next batch. This batching sequence continued until the crater was completed. Once the northwest quadrant was completed, the mixer was repositioned by the southeastern quadrant (Figure 60). The temporary formboard divided the quadrant in half and was anchored in place. Figure 61 shows the team repairing the northeastern quadrant. Note that the finished surface on the southeastern quadrant is reasonably

Figure 60. Repairing the traffic lane in the southeastern quadrant for Crater 5.

Figure 61. Completing the southeastern quadrant in Crater 5.

smooth and free from excess spillage around the edge of the sections (bottom of Figure 61) Periodically during the day, the portable mixer was pulled away to clean out the build-up of RS material on the shaft and paddles. Also, the concrete chute was no longer used as it became cumbersome to reposition and the supports on the top hindered using shovels to move the material down. Following the completion of the southeastern quadrant, the remainder of the traffic lane was completed (the northeastern quadrant), and finally the southwestern quadrant. The test crater repair was completed by 1515 hrs, as shown in Figure 62.

Figure 62. Final crater repair in Crater 5.

Temperature readings

The temperatures recorded in the cap material at the corner and center of the crater are shown in Figure 63 and Figure 64, respectively. The temperatures in the corner reached 160 °F at the surface and 1 in depth. At a depth of 5 in below the surface, the temperatures reached 154 °F after 5-1/2 hrs from the start of the repair. At the center of the test crater, the temperatures were slightly cooler with the maximum temperature of 153 °F at the surface, and 130 °F at 7 in below the surface after 7-1/2 hrs from the start of the repair.

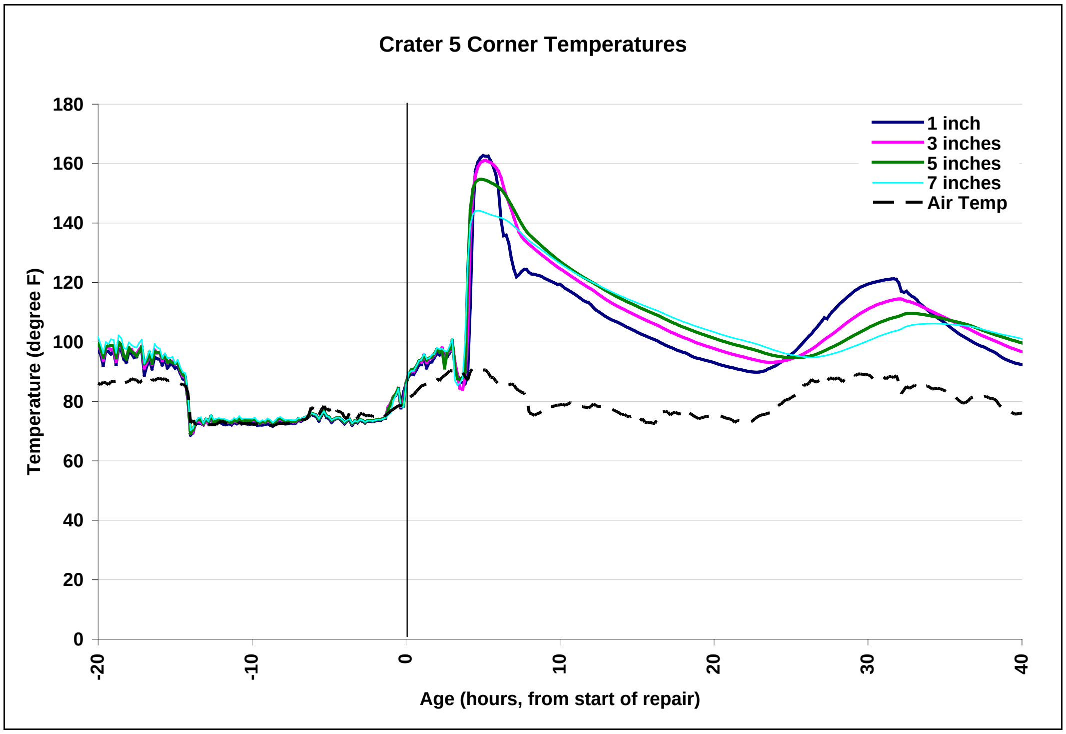


Figure 63. Temperatures in the corner of Crater 5.

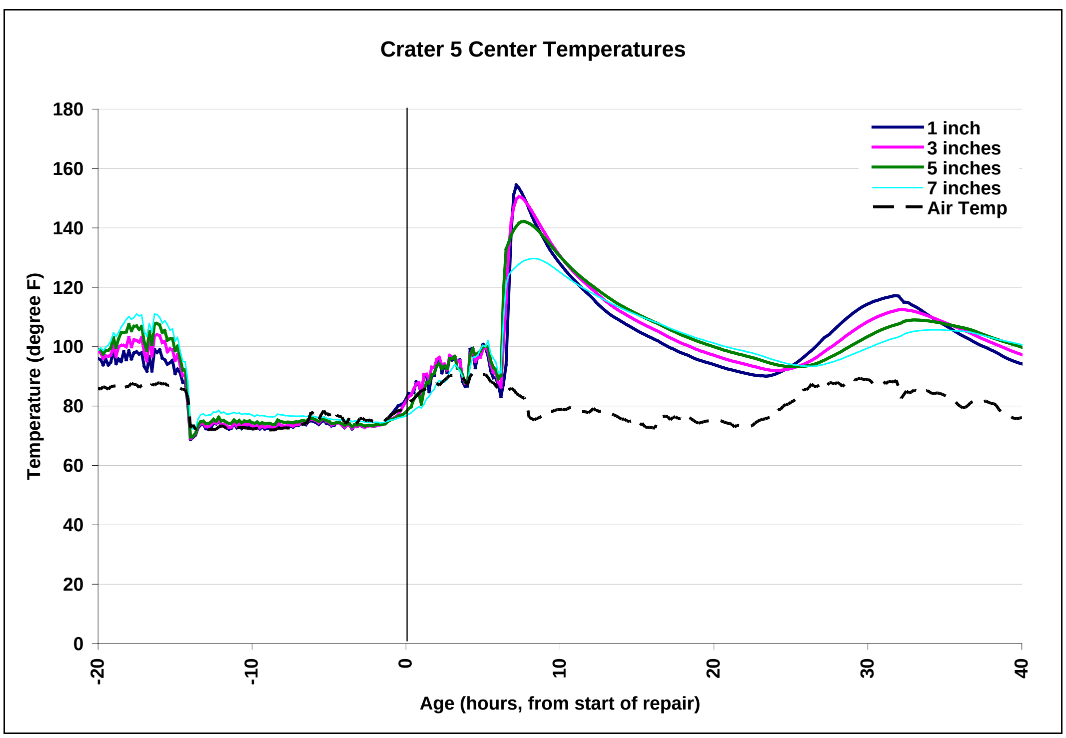


Figure 64. Temperatures in the center of Crater 5.

Moisture readings

The moisture content readings in the base layer from the start of the repair throughout the testing period are shown in Figure 65. The high initial moisture content readings are from moistening the base layer with water. The sharp increases in moisture content readings by the center sensor, which occurred later during the testing period, correspond to rain events, and the material appears to have drained the excess moisture. Aside from the precipitation events, the moisture content remained steady.

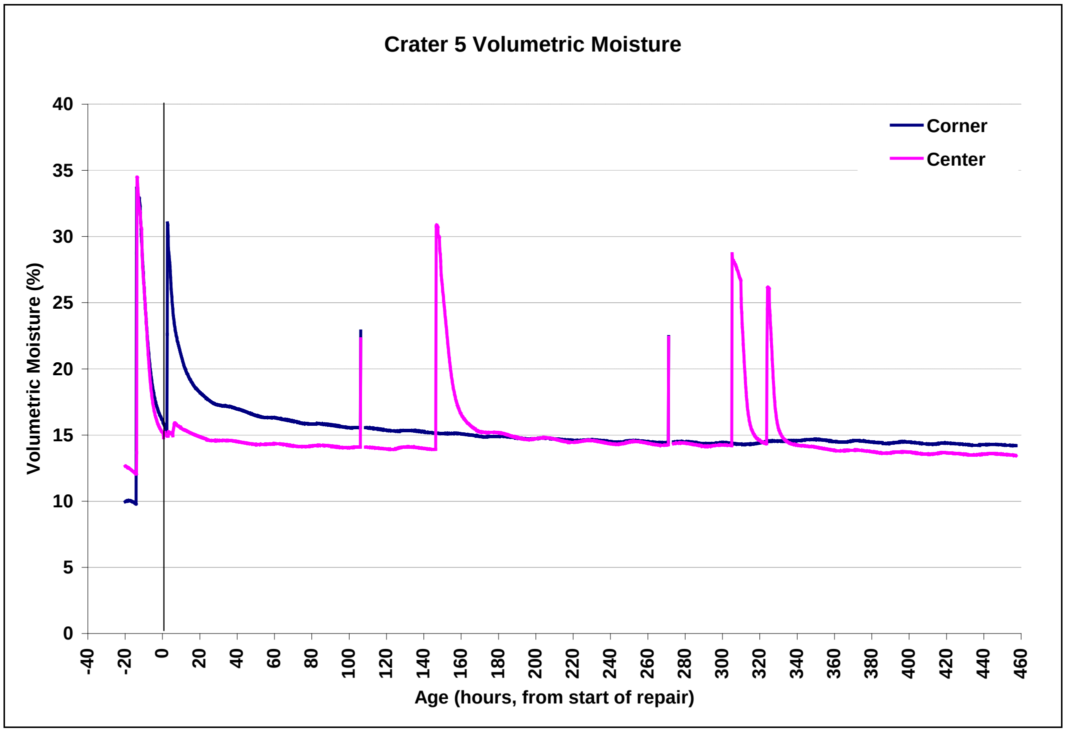


Figure 65. Moisture readings in base layer of Crater 5.

Crater 2 repair–CeraTech, Pavemend EX-H

The Crater 2 repair used Pavemend EX-H, manufactured by CeraTech Inc., an extendable material developed for hot weather. Twenty-nine supersacks, each weighing 2,000 lb were delivered to the site prior to the repair. Initially, the rapid setting material was to be extended with the No. 57 stone. However, as this stone size caused the mixer to jam, each batch of the material was extended using No. 89 stone, acquired from a local source. Each sack called for 28 gal of water. The yield of one supersack of material, extended with the stone and water, was 0.88 yd^3.

Initially, to reduce the number of batches needed to complete the repair, the approach called for two supersacks of material and 2,850 lb of stone to be mixed at one time in the portable mixer. The crater was divided into quadrants using forms – this was completed the previous afternoon using 2 in x 10 in boards. The CeraTech representatives determined that a 6 in layer (instead of 8 in) of RS material would be sufficient for the cap layer of the repair. They opted to spread 2 in of the No. 57 aggregate over the base layer in each quadrant. This was done using the front end loader, multi-terrain loader, hand tools, and was compacted using the vibratory plate compactors. Water from the water truck was added to moisten the aggregate layer. The preparation required about 45 min (Figure 66).

Figure 66. Crater 2 formed and layer of aggregate added.

Batch 1 began at the northwestern corner of the crater at 0710 hr with the addition of 1,400 lb of stone to the mixer and 14 gal of water, followed by one supersack of RS material, and the remaining 14 gal of water. It was mixed for 8 min and discharged into the crater (Figure 67). The temperature of the mix was 93 °F. The same sequence was followed for Batch 2, with the exception that the mixer was overloaded and the paddles stopped turning. The mix was quickly discarded before it set up. The mixer may have become overloaded by adding the cement to the mixer too quickly.

Figure 67. Batch 1 in the northwestern corner of Crater 2.

For Batch 3, the mixer was moved to the southeastern quadrant to begin repairing the traffic lane, and maximize the time for the material to cure prior to trafficking (Figure 68 and Figure 69). The Pavemend EX-H was added first (5 min) via a smaller hole cut into the bottom of the sack using the cutting edge on the portable mixer. All 28 gal of water were added to the RS material (2 min). The aggregate was added slowly with a multi-terrain loader (1 min). The mix time was reduced to 6 min and the mix discharged into the crater. The mix was very fluid and had a temperature of 95 °F. The material was spread using concrete rakes and vibrated with a shaft vibrator. The material already in the crater was beginning to set, so a plate compactor was run over the top in an attempt to prolong the workability, but instead, it tore the material surface.

This mixing sequence was used through Batch number 8. The material in Batch 8 was distributed between the southeastern quadrant (that was screeded with a scrap piece of lumber), and the northeastern quadrant (Figure 70). Once any excess material had been emptied from the mixer, it was removed and cleaned.

Figure 68. Adding Pavemend EX-H to the mixer for Batch 4 for Crater 2.

Figure 69. Southeastern quadrant of Crater 2 after placing two batches of material.

Figure 70. Screeding and floating the southeastern quadrant of Crater 2.

The initial mixes were fairly fluid, yet as the daytime air temperature and material temperatures warmed, successive batches became increasingly stiffer. The mix was adjusted by reducing the amount of stone to approximately 1,200 lb (a level bucket instead of a slightly rounded bucket load), and adjusting the mix water to 31 gal per batch.

A quadrant size was too large to pour, therefore the northeastern quadrant was divided in half using a temporary form (2 in x 10 in piece of lumber). Batches 9 through 11 were placed in the northeastern quadrant. Batch 11 was very dry, with some of the material sticking to the chute. It was spread with concrete rakes while two airmen attempted to screed and vibrate the material (Figure 71). However, the mix had set and the material from Batch 11 was removed following the vendor's recommendation (Figure 72). As shown in the photograph, the removal resulted in a tear at the corner of the previous section. The operation was suspended for 40 min while the vendor representatives determined how to adjust the fast-setting mixes.

The crater repair resumed at 1210 hrs with the mixer positioned on the north side of the northeastern quadrant. The mix was adjusted by adding more water per batch, for a total of 34 gal per supersack of RS material. Once the northeastern section was completed, the mixer was re-positioned to repair the southwestern section, and finally the northwestern section

Figure 71. Attempt to finish Batch 11 before it sets up and workability is lost in Crater 2.

Figure 72. Removal of material from Batch 11 and damage to adjacent section in Crater 2.

was repaired. The last mix, Batch 26, was discharged into the northwest section and the surface finished by 1600 hr. The small crater adjacent to the southwestern quadrant was also filled in with material. The photograph in Figure 73 shows the material layers in the southwestern quadrant. Figure 74 shows the completed repair. The total time required to complete the repair in Crater 2 was nearly 10 hr, including the time required to set the formwork and place the stone base layer.

Figure 73. Layering of material poured in southwestern section of Crater 2.

Figure 74. Final surface of the Pavemend EX-H repair for Crater 2.

Temperature readings

Temperature readings are shown at the center and corner locations in Figure 75 and Figure 76, respectively. At the center location, the maximum recorded temperature was 130 °F at 1 in depth, near the surface, after 13 hr from the start of the repair. At 5 in below the surface, the maximum temperature reached 125 °F. This location was just near the bottom of the cap material. The sensor at 7 in below the surface was located in the aggregate layer and the readings reached 110 °F. The temperature readings at the corner location were higher. The maximum recorded temperature of 146 F was reached 8 hrs after the start of the repair in Crater 2.

Moisture readings

The volumetric moisture readings are shown for both the center and corner sensor in Figure 77. The measurements remained relatively constant throughout the testing period, except for the spikes from rain events later in the performance testing.

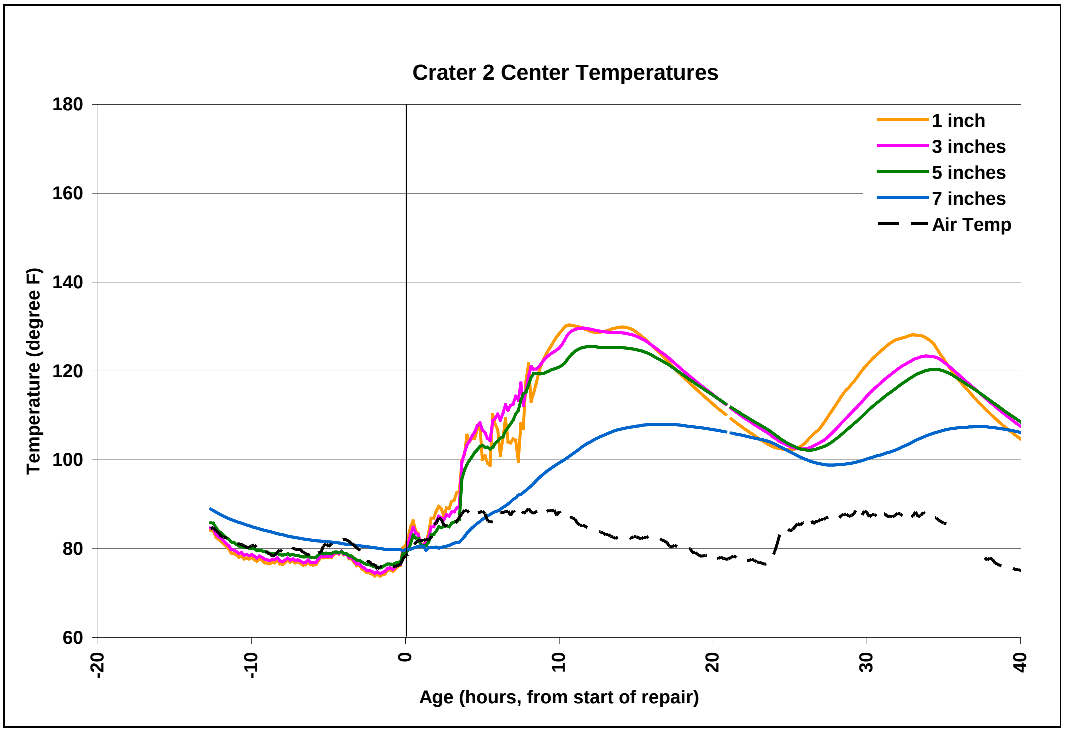


Figure 75. Temperature readings from center location of sensors in Crater 2.

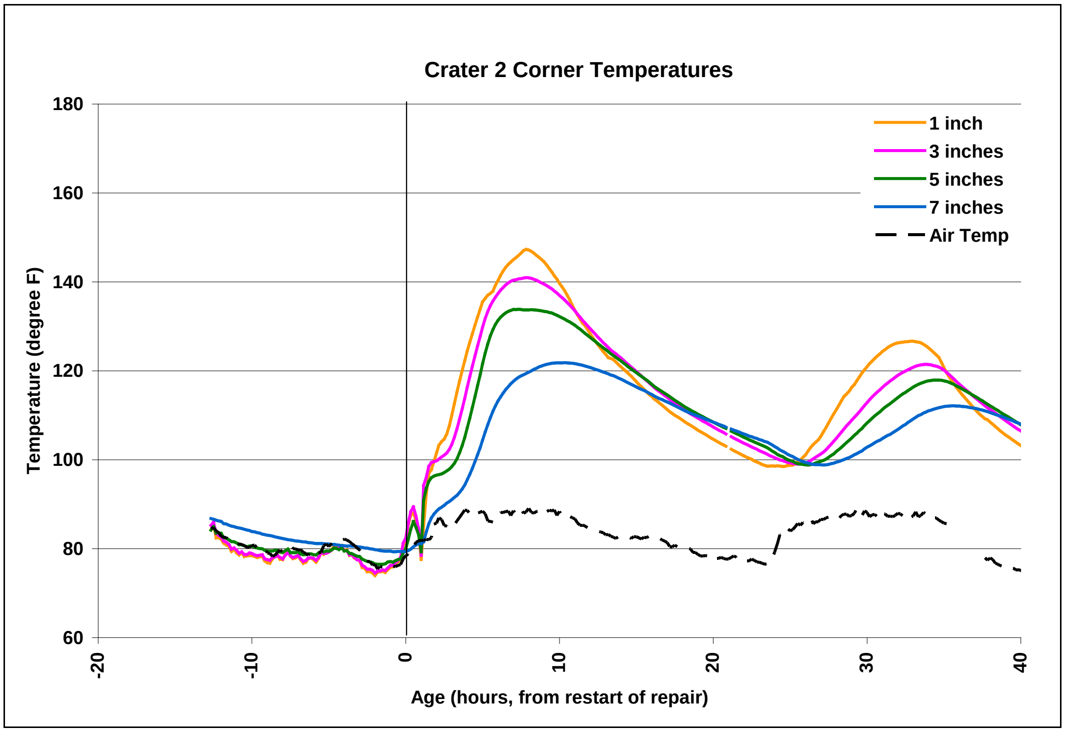


Figure 76. Temperature readings from southeastern corner location of sensors in Crater 2.

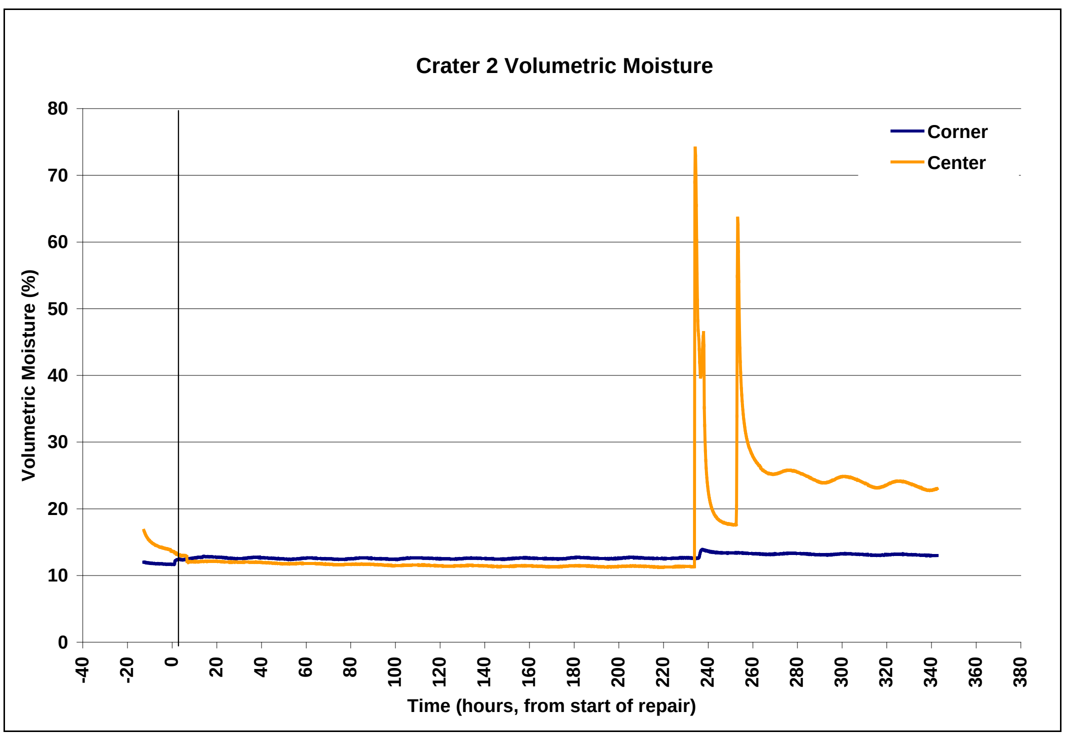


Figure 77. Moisture readings from both center and corner locations in Crater 2.

Crater 4 repair–Ultimax™ Cement, Ultimax Concrete

This repair consisted of the Ultimax™ Cement Ultimax Concrete material. The concrete mix was pre-proportioned in 3,000 lb supersacks with cement, sand, and stone, requiring only the addition of 50 gal of water. The repair approach was to mix two supersacks (6,000 lb) at one time in the portable mixer using a crew size of twelve airmen.

Prior to the start of mixing, the crater was prepared by first pre-wetting the base material with 100 gal of water, and installing stay-in-place forms (also used in Crater 3). The Ultimax Concrete representatives decided to use the aluminum stay-in-place forms for the repair. The aluminum forms consisted of 10 ft lengths held in place with stakes. The top rim of the form attached to the top of the stakes. The forms connect together with thin aluminum tabs that slide under the top rim of the form (Figure 78).

Figure 78. Stay-in-place aluminum forms with connecting tab used in Crater4 (Crater 3, too).

Different techniques were attempted to quickly install the stakes. Initially, hand tools (hammers or small sledge hammers) were used to install the stakes. However, the base material was too stiff, bending the stakes (Figure 79), and making it difficult to position the form piece vertically. The most efficient method was to use an electric rock drill with a 1 in drill bit to create a pilot hole and then hammer the stake in (Figure 80).

Figure 79. Bent aluminum stakes resulted from the use of hand tools during the installation of stay-in place forms in Crater 4.

Figure 80. Drill used to make pilot hole to install form stake in Crater 4.

The repairs for Craters 5 and 2 showed that dividing the crater into four quadrants posed a volume too large to fill using the multiple, smaller batches from the portable mixer. Since both of those repairs ended up partitioned into eight sections, Crater 4 was divided into eight sections measuring 15 ft by 7-1/2 ft, using a string line and marking the locations for the forms with spray paint. Three full-length, uncut forms were positioned in a transverse direction in the crater (East-West). The forms in the longitudinal direction (North-South) were placed as close to the center as possible so as to not interfere with the instrumentation, and were trimmed to fit using tin snips. The total time required to place the forms was 2 hr and 40 min (Figure 81).

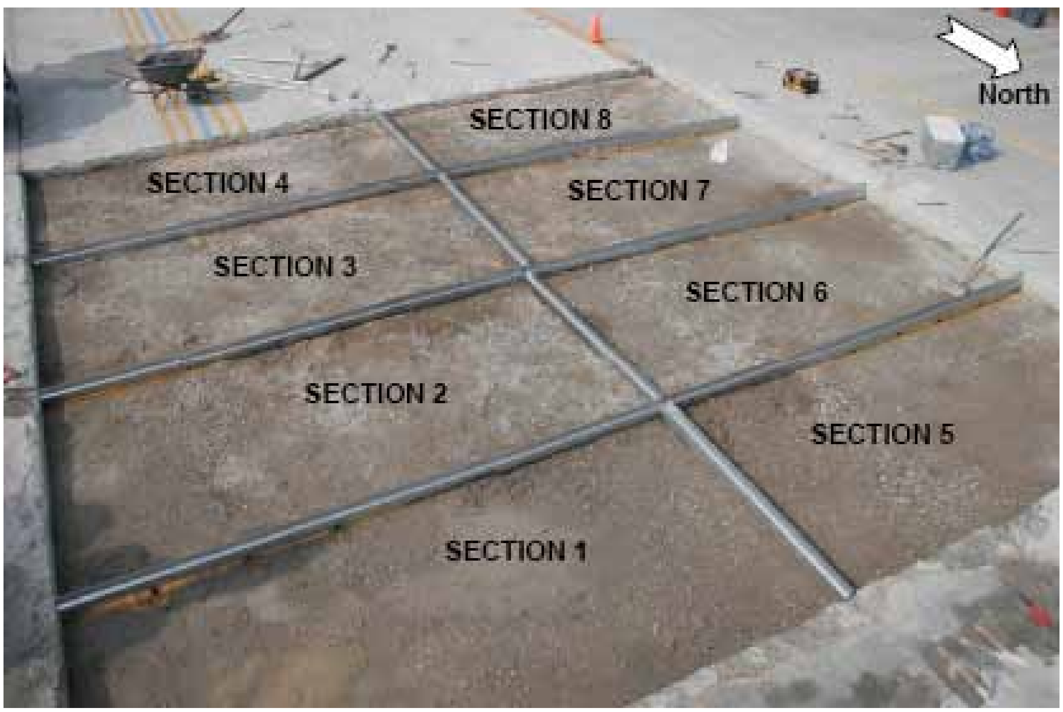


Figure 81. Completion of Crater 4 preparation.

Next, the base material in the northeastern section was pre-wet with another 4 gal of water. At 0911 hr the first batch of Ultimax Concrete was started by adding one supersack of Ultimax Concrete mix to the mixer (Figure 82), followed by 35 gal of water. An additional 15 gal of water was added for a total of 50 gal of water for one supersack. A second supersack of Ultimax Concrete mix was added to the mixer along with 45 gal of water. Three minutes later, after all of the cement had been added, another 5 gal of water was added. There were 2 yd^3 of material being mixed in the mixer. This was the largest quantity of material mixed at one time in the portable mixer during any of the test crater repairs, as well as the highest

quantity of mix water used. The material was mixed for 3 min and discharged into the northeastern section of the crater. The total time to load, mix, and pour the batch was 15 min. The material was very fluid, with fist-sized lumps of unmixed material (Figure 83).

Figure 82. Adding Ultimax concrete to the mixer for Crater 4.

Figure 83. Batch 2 of Ultimax concrete, containing lumps of unmixed material, placed into Section 2 of Crater 4.

The amount of water added to the first supersack for Batch 2 was increased to 75 gal. The neck at the bottom of the supersack hampered the flow of the RS material into the mixer. Notches were cut in the sides of the supersack to increase the flow. This also helped to distribute the material more evenly over the length of the mixer for better mixing, instead of concentrating the mix in the center. After 22 min, half of the second batch was placed into the northeastern corner over the 1st batch to complete the section. The material was spread with concrete rakes, vibrated with a shaft vibrator, screeded with a scrap piece of lumber (2 in x 4 in) (from East to West), and finished with a bull float. Section 1 was completed by 1021 hrs. As the mixer was being repositioned to repair Section 2, the base material was moistened with several gallons of water just prior to the placement of the remaining material from Batch 2.

The wear-and-tear on the portable mixer was evident as the back gate on the mixer was sticking, making it difficult to manually close and open to continue the mixing operation. A sledgehammer was used to control the gate opening and this amount of force on the mechanism would prove problematic later in the day.

At 1000 hrs, another supersack of concrete mix was added to the mixer along with 10 gal of water (Batch 3). The water truck then ran out of water. The material was quickly setting up, and was immediately discharged. In spite of this, enough material had hardened inside the mixer on the paddles and side walls to impede mixing. This required the hardened material to be chiseled and broken out in pieces. Removal of the hardened material required about 2 hr and 45 min. No. 4 rock and water were run through the mixer to abrade the inside of the mixer. Section 2, was half-filled and the material had set.

Although Section 2 was only partially complete, the material placed before the portable mixer jammed had set and was too warm to place more material on top. At 1300 hr, the operation continued by positioning the mixer and pre-wetting the base in Section 3. For Batch 4, 75 gal of water were added to the mixer simultaneously with the first supersack of concrete mix. The remaining mix water was added with the second supersack, for 50 gal of water per sack. At 1320 hrs, the mix was discharged into Section 3. Adding some of the mix water before adding the Ultimax Concrete mix reduced the unmixed lumps. Batch 5 was mixed similarly and discharged into the repair. To complete Section 2, the surface was

sprayed with water, and a portion of Batch 6 and all of Batch 7 were used to fill the section, with the remaining material discharged into Section 4 (southeastern corner, Figure 84 and Figure 85). Before mixing Batch 8, some time was used to clean the mixer.

Figure 84. Section 2 of Crater 4 was filled with a portion of the material from Batch 6.

Figure 85. Completed Sections 1 through 4 of Crater 4.

The crater repair continued in the northwestern corner (Section 5) foll-owed by Sections 6 through 8. A problem with the hydraulics on the mixer motor occurred, possibly due to blown seals, while discharging Batch 12 into Section 7. The mix size was reduced to one supersack of concrete mix in the next batch and 55 gal of water. The mix was very fluid. Larger clu-mps of unmixed material, roughly softball size, were present after mixing. Material had built-up on the paddles and shaft (Figure 86), so the mixer pulled away from the test crater to be checked and cleaned. After cleaning, the operation returned to mixing 2 supersacks per batch.

Figure 86. Breaking up large clumps of unmixed Ultimax concrete material building up on the center shaftwith a ball-peen hammer.

While using the sledgehammer to close the gate, the bolt on the handle sheared, rendering the mixer inoperable. At this point, the final section, Section 8, was underfilled by roughly ½ yd following Batch 15. About 300 lb of No. 4 rock was placed in Section 8 to complete the repair. The section was floated and finished by 1805 hrs. Including the time needed to remove the hardened material out of the mixer, 11 hrs and 30 min were needed to complete Crater 4. Excluding the 2 hr and 45 min required to restore the mixer when the water truck ran out of water, the total time for the repair was 8 hr and 45 min. A photograph of the completed repair in Crater 4 is shown in Figure 87.

Figure 87. View of the completed repair in Crater 4.

Temperature readings

The corner thermocouple string was located in the southeastern corner in Section 4 and reached a maximum temperature of 155 °F at 3 in depth about 10 hr from the start of the repair (Figure 88). After the forms were placed, the center thermocouple string was located in the northeastern corner of Section 7. The readings from both the 5 and 7 in depths appear to be from some material that seeped through the forms while pouring Section 3. The maximum temperature was 143 °F reached 13 hr after the start of the repair (Figure 89).

Moisture readings

The increase in the moisture readings from both sensors occurred when the base material was moistened during the repair (Figure 90). No other changes in moisture were observed during the testing period.

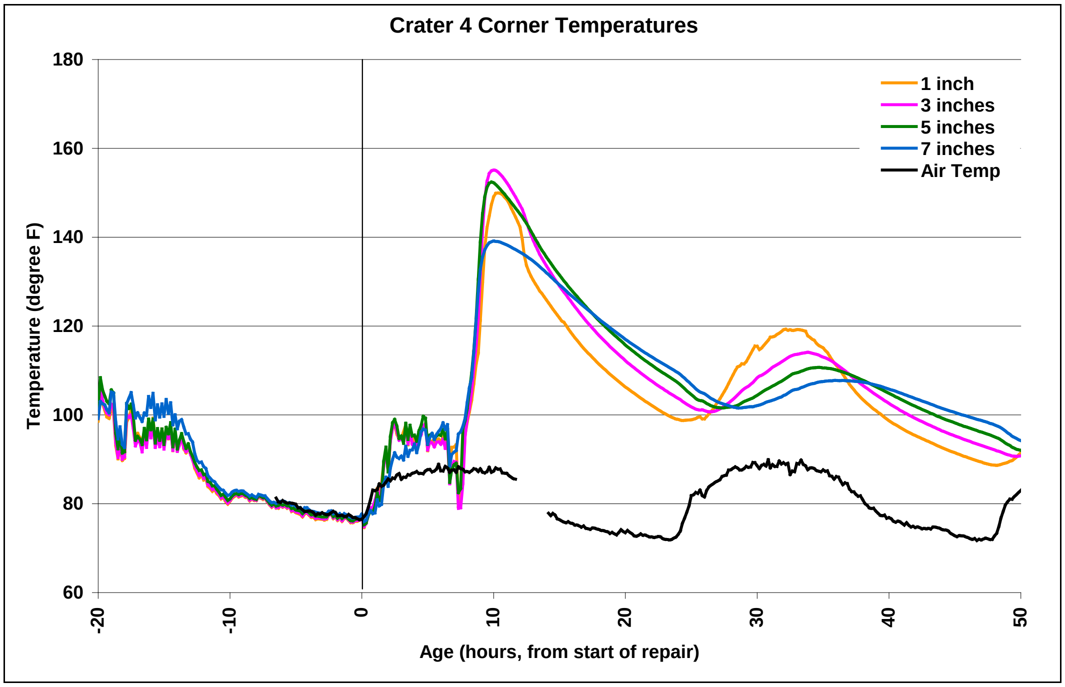


Figure 88. Temperature history at southeastern corner of Crater 4.

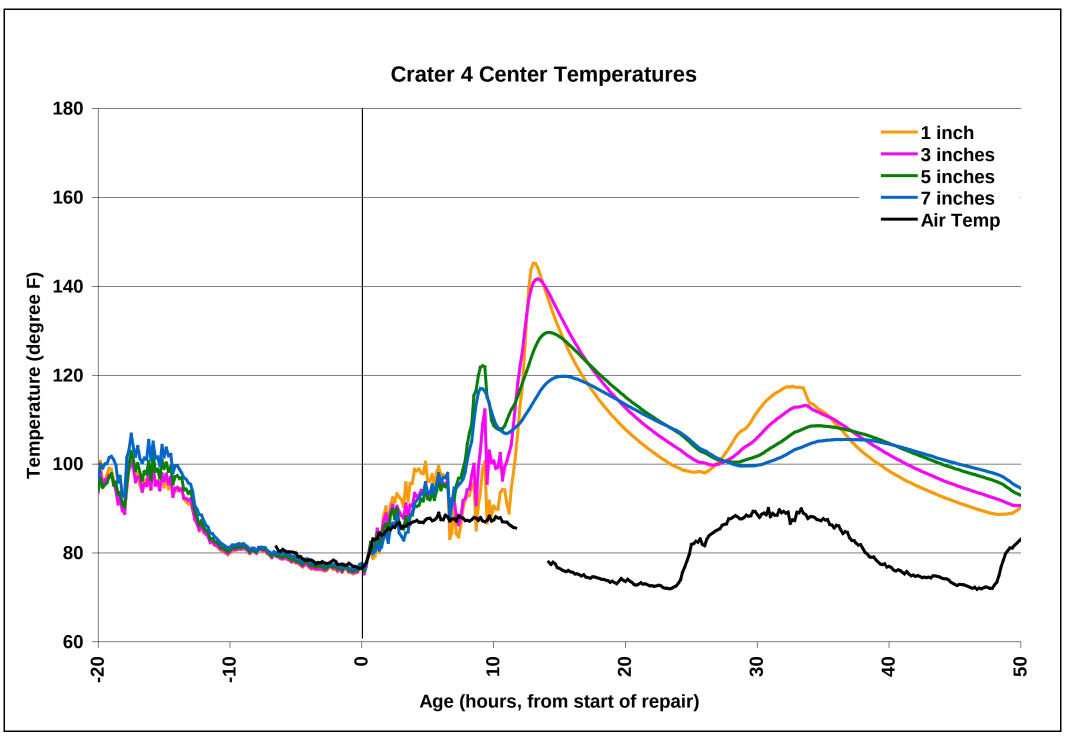


Figure 89. Temperature history at center of Crater 4.

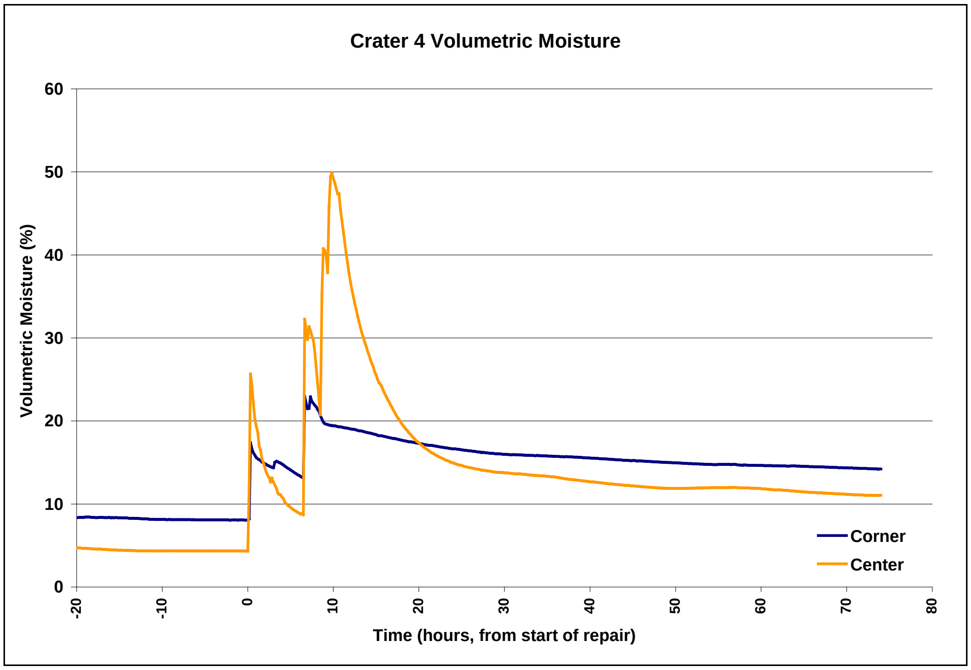


Figure 90. Moisture readings from Crater 4.

Crater 3 repair–Ultimax™ Cement, Aquacrete

Crater 3 was repaired with the Aquacrete material, manufactured by Ultimax™ Cement. This was the final repair conducted during the full-scale field testing program. The portable mixer was rendered inoperable at the completion of the previous repair. As a result, the Aquacrete material was mixed using a standard ready-mix truck, rented locally. Stay-in-place aluminum forms were installed in the crater the previous day (at the same time the forms were installed in Crater 4, as discussed in the *Crater 4 repair* section), this time, dividing the crater into four quadrants (Figure 91). Like Crater 4, a hammer drill had been used to pre-drill the holes to install the stakes in Crater 3. Installation of the forms required approx-imately 1 hr to complete. Next, the No. 4 rock was placed in the quadrants, to a depth 2 in below the existing pavement surface, using the multi-terrain loader with 3 airmen spreading the material. The rock was not compacted.

At the staging area at 0940 hr on the morning of the repair, the ready-mix truck was charged with mix water. The Aquacrete material used 125 gal of water per supersack. A total of 600 gal of water was added to the truck along with five supersacks of Aquacrete, each weighing 3,650 lb (Figure 92). This required about 20 min. The material was mixed in the truck and discharged into the northeastern quadrant. The mix was very fluid and

overflowed into the northwestern quadrant (Figure 93). A multi-terrain loader was used to add more rock to the northeast quadrant. By 1037 hr, the first batch of Aquacrete had been discharged from the truck (Figure 94). The truck returned to the staging area for the next batch.

Figure 91. Photograph at the center of Crater 3 showing the stay-in-place forms and the #4 rock.

Figure 92. Adding Aquacrete to truck for Crater 3.

Figure 93. Aquacrete overflowing out of northeast quadrant of Crater 3.

Figure 94. View of Crater 3 following first batch of Aquacrete.

For the 2nd batch, 700 gal of water was added to the truck from 1046 to 1102 hr. Seven bags of Aquacrete were added to the truck, requiring an additional 30 min. After the Aquacrete was added, an additional 40 gal of water were added. At 1140 hrs, the material for Batch 2 was discharged into the southeastern quadrant of Crater 3. The material was so fluid that a wooden pallet was used to aid in reducing the splatter as the material was discharged down the chute. With most of the material discharged from the

truck, the top of the Aquacrete repair was still 2 in below the existing surface near the centerline of the runway, due to the slope of the runway (Figure 95). Discharging the material was stopped to further agitate the material to reduce its fluidity. At 1150 hrs, the material gelled and became too thick to place (Figure 96). The remainder of the material flash set in the mixer drum.

Figure 95. The repair material in Crater 3 is approximately 2 in below the existing pavement surface.

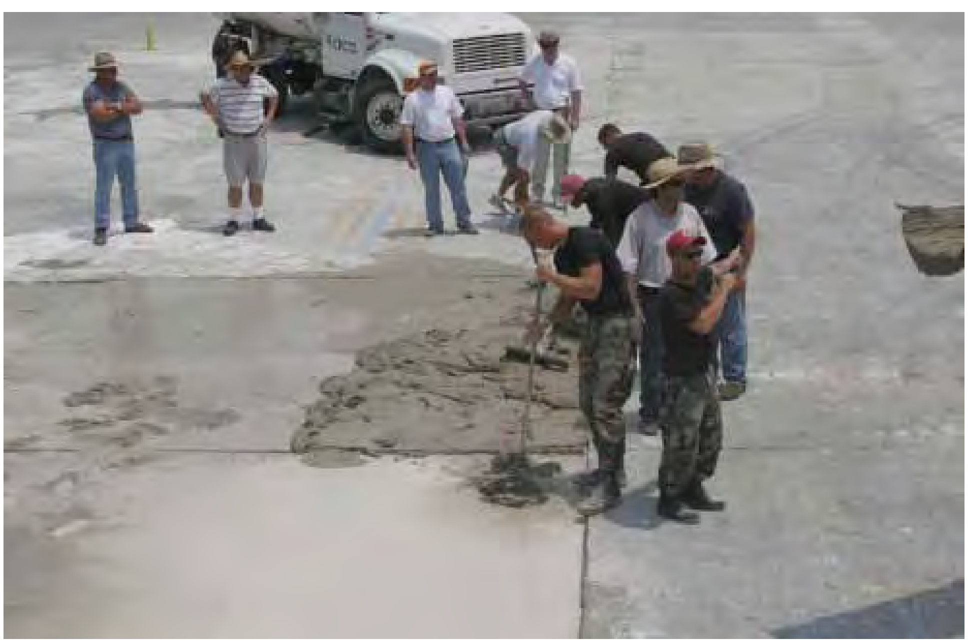


Figure 96. Gelled Aquacrete material could not be placed in Crater 3.

Attempts were made to transfer some of the material into the traffic lane to build it up to the level of the existing pavement with a multi-terrain loader, but the material was setting up, making it too difficult to either move or finish. Exposed edges of the stay-in-place forms within the traffic lane presented too much of a hazard to the aircraft tire and rendered the section untrafficable. Therefore, it was determined that Crater 3 would not be trafficked with the load cart (Figure 97). A total of 13 supersacks of material and 3 hr were used for the incomplete repair. No temperature or moisture data are presented for this incomplete repair.

Figure 97. Final Crater 3 repair surface.

Field Quality Control Testing

During each crater repair, 6 in x 12 in compressive strength cylinders were cast from the material batches during the placement (Figure 98). Once cast, the cylinders were covered with plastic to maintain moisture and to protect them from direct sun exposure. The Air Force Research Laboratory (AFRL) tested the cylinders in their materials testing laboratory at early test ages of 2 and 24 hr. The test station is shown in Figure 99.

Figure 98. Casting strength cylinders during the full-scale field trial.

Figure 99. AFRL testing equipment for unconfined compressive strength.

Craters 1 and 3 both utilized pre-placed No. 4 aggregate and a flowable, grout-type mixture as the binder. Laboratory strength cylinders were cast by pre-placing some of the No. 4 rock in the bottom of the cylinder and allowing either the grout or the Aquacrete material to percolate through the voids between the stone. The cylinders were tamped several times to release any entrapped air.

Compressive strength

The test results, shown in Figure 100 for the 2 hr test age and Figure 101 for the 24 hr test age, are average values. All compressive strength test results at 2 and 24 hr are listed in Table 14 and Table 15 respectively.

For Crater 1, the stone and grout material, the testing age was 24 hr. One set of cylinders was cast with pre-placed aggregate, and the other was cast with the grout mixture only (neat). The RS materials were tested at ages of 2 and 24 hr. Two cylinders were tested at 3 hr: one from Rapid Set DOT cement (Crater 6), and Pavemend EX-H (Crater 2). When two of the Pavemend EX-H materials tested very low at the 2 hr age, the test age of the last cylinder age was lengthened to 3 hr. Two cylinders were cast from the Ultimax Aquacrete material.

Discussion of large-scale crater repairs

The purpose of the full-scale field trial was to repair the structural cap layer of simulated large craters using commercial RS materials. The time-frame used within which to complete the repair was the current NATO standard of 4 hr. A total of 6 simulated craters were prepared, with each repair utilizing a different commercial material.

The time required to complete each repair and major tasks are summarized in Table 16. The required time began from the repair and does not include breaking out and constructing the craters. For each crater repair, preparation time of approximately an hour was required for each crater. With the exception of stone and grout method used for Crater 1, the remaining craters made use of formwork to divide the cap volume. The use of pieces of lumber was a straight-forward approach, as compared to the stay-in-place forms. The lumber was reused in the repair of other craters. Nevertheless, the airman and soldiers quickly overcame the untried aluminum forms and, with the right tools, improved the installation method.

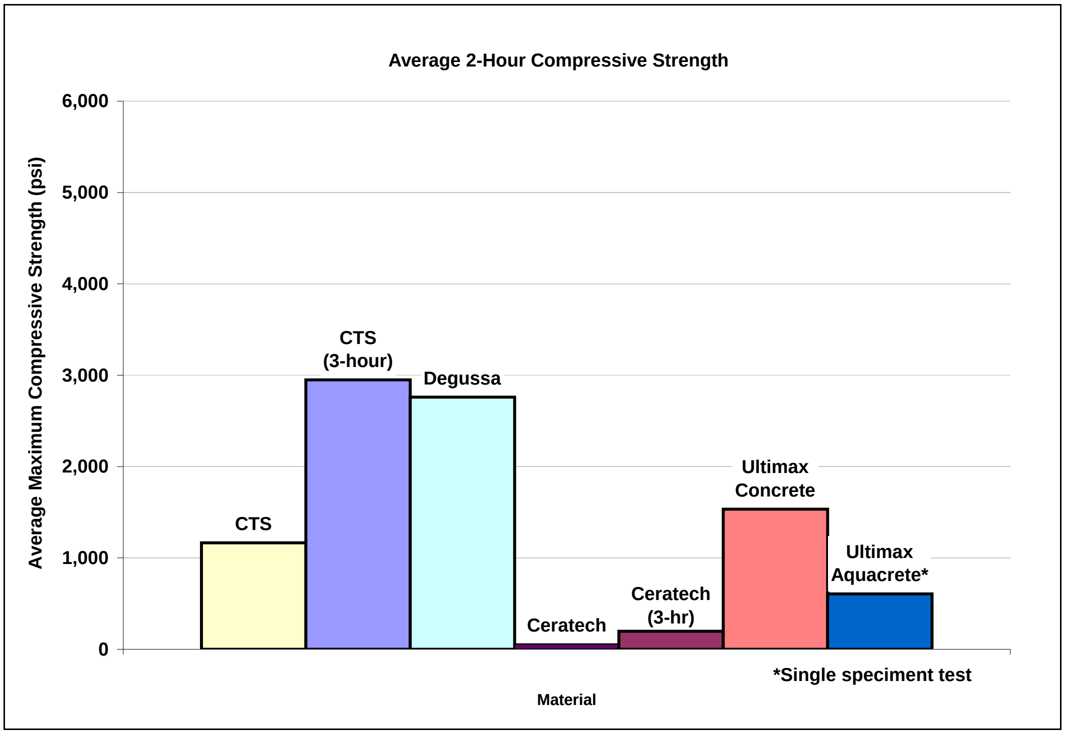


Figure 100. Results of 2 hr average compressive strength tests on field cast cylinders.

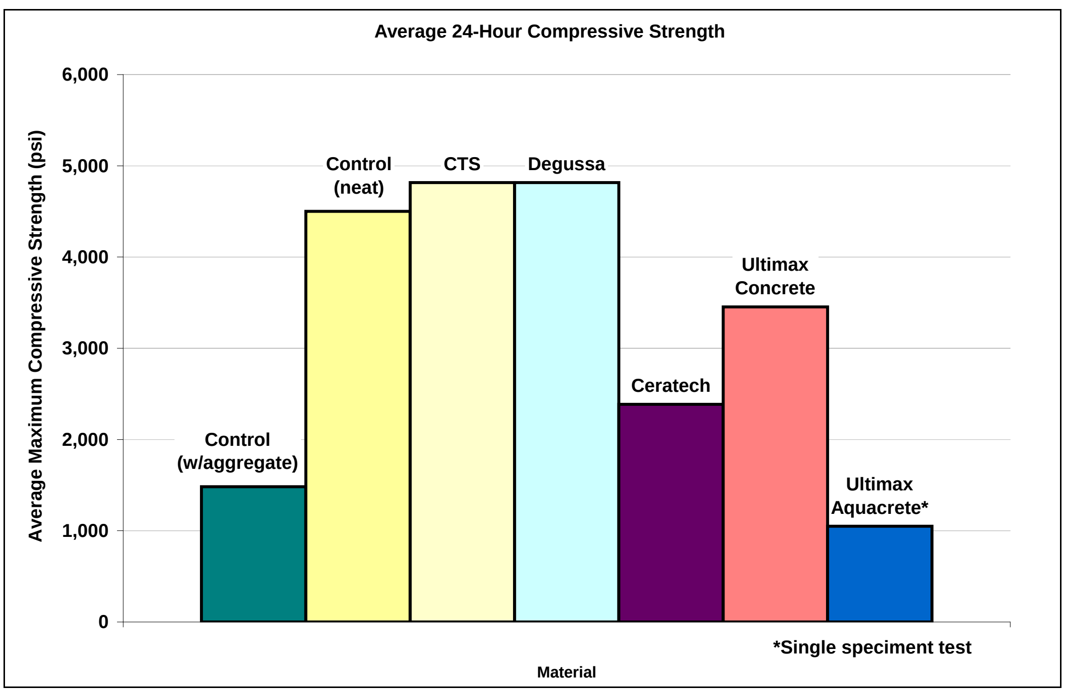


Figure 101. Results of 24 hr average compressive strength tests on field cast cylinders.

Table 14. Results of 2 hr compressive strength testing on field cast cylinders.

Sample Name	Notes	Test type	Max Load Rate **(Goal Load Rate of 1000 pounds / second)**	Test Date & Time	Pre-start Load, LBS.	Max Recorded Load, LBS.	Net Load, LBS.	Max Compressive Strength of sample, P.S.I.
Batch 1, CTS Cement, 10:44 06/22/2006 **A**	Both ends capped, **with aggregate,** brief moment of high rate while dialing in.	2 Hour Compressive	1452 lbs/sec	06/22/2006, 12:32:00 PM	10.00	32,430.00	32,420.00	**1,146.80**
Batch 3, CTS Cement, 13:36 06/22/2006 **A**	Both ends capped, **with aggregate**	3 Hour Compressive	1108 lbs/sec	06/22/2006, 4:31:00 PM	10.00	83,380.00	83,370.00	**2,949.06**
Batch 4, CTS Cement, 14:30 06/22/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	946 lbs/sec	06/22/2006, 4:45:00 PM	0.00	33,460.00	33,460.00	**1,183.59**
Batch 3, Degussa, 09:00 06/24/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	1067 lbs/sec	06/24/2006, 11:00:00 AM	10.00	74,630.00	74,620.00	**2,639.55**
Batch 8, Degussa, 10:56 06/24/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	1056 lbs/sec	06/24/2006, 13:13	10.00	84,650.00	84,640.00	**2,993.99**
No batch number, Degussa 14:10, 06/24/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	1092 lbs/sec	06/24/2006, 15:59	20.00	74,920.00	74,900.00	**2,649.45**
Batch 5, Ceratech 08:39, 06/27/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	46 lbs/sec	06/27/2006, 10:43	0.00	1,950.00	1,950.00	**68.98**
No batch #, Ceratech 12:44, 06/27/2006 **A**	Both ends capped, **with aggregate**	3 Hour Compressive	205 lbs/sec	06/27/2006, 15:50	10.00	5,560.00	5,550.00	**196.32**
Batch 21, Ceratech, 14:51 06/27/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	33 lbs/sec	06/27/2006, 16:50	10.00	1,310.00	1,300.00	**45.99**
Batch 4, Ultimax, 13:25, 06/28/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	1100 lbs/sec	06/28/2006, 15:24	20.00	41,730.00	41,710.00	**1,475.42**
Batch 7, Ultimax, 14:20, 06/28/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	950 lbs/sec	06/28/2006, 16:19	10.00	41,690.00	41,680.00	**1,474.35**
Batch 10, Ultimax, 16:02, 06/28/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	1000 lbs/sec	06/28/2006, 17:58	0.00	46,710.00	46,710.00	**1,652.28**
Batch 10, Ultimax, Aquacrete, 10:40, 06/29/2006 **A**	Both ends capped, **with aggregate**	2 Hour Compressive	Max achieved was 308 lbs/sec, fluctuated wildly	06/29/2006, 12:41	0.00	17,110.00	17,110.00	**605.24**

Table 15. Results of 24 hr compressive strength testing on field cast cylinders.

Sample Name	Notes	Test type	Max Load Rate **(Goal Load Rate of 1000 pounds / second)**	Test Date & Time	Pre-start Load, LBS.	Max Recorded Load, LBS.	Net Load, LBS.	Max Compressive Strength of sample, P.S.I.
Control, Batch 3 6/20/06, 13:55 Neat (No label) **Actually had aggregate - not neat**	Both ends of the sample were capped, failed quickly, could not achieve desired load rate	24 Hour Compressive	600 lbs/sec	06/21/2006, 1:54:00 PM	20.00	21,050.00	21,030.00	**743.90**
Control, Batch 3 6/20/06, 13:55 Neat B	Both ends of the sample were capped	24 Hour Compressive	1021 lbs/sec	06/21/2006, 2:08:00 PM	10.00	79,710.00	79,700.00	**2,819.24**
Control, Set 2 06/20/06, 14:35	Both ends capped, neat (no aggregate)	24 Hour Compressive	1092 lbs/sec	06/21/2006, 2:25:00 PM	10.00	80,470.00	80,460.00	**2,846.13**
Control, Set 2 06/20/06, 14:35 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1096 lbs/sec	06/21/2006, 2:35:00 PM	10.00	62,780.00	62,770.00	**2,220.37**
Control, Set 3 06/20/06, 16:18 Flood	Both ends capped, neat (no aggregate)	24 Hour Compressive	1075 lbs/sec	06/21/2006, 4:00:00 PM	10.00	167,850.00	167,840.00	**5,937.04**
Control, Set 3 06/20/06, 16:18 Flood **B**	Both ends capped, neat (no aggregate)	24 Hour Compressive	1071 lbs/sec	06/21/2006, 4:13:00 PM	10.00	181,010.00	181,000.00	**6,402.55**
Batch 1, CTS Cement, 10:44 06/22/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1108 lbs/sec	06/22/2006, 10:49:00 AM	10.00	160,680.00	160,670.00	**5,683.41**
Batch 3, CTS Cement, 13:36 06/22/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1067 lbs/sec	06/23/2006, 10:49:00 AM	0.00	127,240.00	127,240.00	**4,500.88**
Batch 4, CTS Cement, 14:30 06/22/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1117 lbs/sec	06/23/2006, 10:49:00 AM	10.00	120,520.00	120,510.00	**4,262.82**
Batch 3, Degussa, 09:00 06/24/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1052 lbs/sec	06/25/2006, 09:02	20.00	91,660.00	91,640.00	**3,241.60**
Batch 8, Degussa, 10:56 06/24/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1075 lbs/sec	06/25/2006, 10:55	0.00	89,970.00	89,970.00	**3,182.53**
No batch number, Degussa 14:10, 06/24/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1050 lbs/sec	06/25/2006, 13:57	10.00	89,120.00	89,110.00	**3,152.10**
Batch 5, Ceratech 08:39, 06/27/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1045 lbs/sec	06/28/2006, 08:39	0.00	83,580.00	83,580.00	**2,956.49**
No batch #, Ceratech 12:44, 06/27/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1054 lbs/sec	06/28/2006, 12:44	10.00	61,580.00	61,570.00	**2,177.93**
Batch 21, Ceratech, 14:51, 06/27/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1171 lbs/sec	06/28/2006, 14:51	0.00	57,120.00	57,120.00	**2,020.52**
Batch 4, Ultimax, 13:25, 06/28/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1046 lbs/sec	06/29/2006, 13:32	10.00	102,580.00	102,570.00	**3,628.23**
Batch 7, Ultimax, 14:20, 06/28/2006 **B**	Both ends capped, **with aggregate**	24 Hour Compressive	1054 lbs/sec	06/29/2006, 14:24	10.00	91,990.00	91,980.00	**3,253.63**
Batch 10, Ultimax, 16:02, 06/28/2006 **A**	Both ends capped, **with aggregate**	24 Hour Compressive	1046 lbs/sec	06/29/2006, 15:53	0.00	98,310.00	98,310.00	**3,477.54**
Batch 10, Ultimax, Aquacrete, 10:40, 06/29/2006 **B**	Both ends capped, **with preplaced aggregate**	24 Hour Compressive	629 lbs/sec max achieved, fluctuated wildly	06/30/2006, 10:42	10.00	29,660.00	29,650.00	**1,048.81**

Table 16. Comparison of time required to complete each crater repair.

CRATER 1 - CONTROL, STONE AND GROUT							
			TOTAL HOURS	PREP HOURS	REPAIR HOURS	NON-REPAIR HOURS	
Adjusted hours for repair			**7.4**	**1.7**	**5.7**		
Total hours			**11.9**	**1.7**	**5.7**	**4.5**	
Start	**End**	**DAY**					**ACTIVITY**
			1.0	1			Prior to 20JUN - Placed sand layer, compacted & placed vapor barrier
6/20/06 8:00	6/20/06 12:30	0.188	4.5			4.5	**START -** Test batch in mixer & hydraulic leak
6/20/06 12:30	6/20/06 13:15	0.031	0.8		0.8		Placed thin layer of rock in bottom of crater / Pre-wet aggregate
6/20/06 13:15	6/20/06 16:44	0.145	3.5		3.5		Mixing operation started
6/20/06 16:44	6/20/06 17:54	0.049	1.2		1.2		Screed set up & positioned on East side
6/20/06 17:54	6/20/06 18:15	0.015	0.3		0.3		Mixer pulled away / hand finishing surface / **END** of repair
6/21/06 9:43	6/21/06 10:24	0.028	0.7	0.7			21JUN - saw cutting joints
6/21/06 14:20							2-hr Baseline HWD testing

CRATER 2 - CERATECH, PAVEMEND EX-H							
			TOTAL HOURS	PREP HOURS	REPAIR HOURS	NON-REPAIR HOURS	
Adjusted hours for repair			**9.7**	**0.8**	**8.9**		
Total hours			**9.7**	**0.8**	**8.9**	**0.0**	
Start	**End**	**DAY**					**ACTIVITY**
			0.8	0.8			Prior to 27JUN - Set forms, placing and compacting stone for base layer
6/27/06 7:10	6/27/06 16:02	0.369	8.9		8.9		START - Crater repair - Pre-wet base course layer, position mixer at Northwest quadrant. Add stone, water, and dry material to mixer and continued until repair completed
6/27/06 18:15							2-hr Baseline HWD testing

CRATER 4 - ULTIMAX CEMENT, ULTIMAX CONCRETE							
			TOTAL HOURS	**PREP HOURS**	**REPAIR HOURS**	**NON-REPAIR HOURS**	
Adjusted hours for repair			**8.5**	**2.7**	**5.8**		
Total hours			**11.6**	**2.7**	**5.8**	**3.1**	
Start	**End**	**DAY**					**ACTIVITY**
6/28/06 6:30	6/28/06 9:10	0.111	2.7	2.7			START - Pre-wet base layer & install stay-in-place forms
6/28/06 9:10	6/28/06 10:00	0.035	0.8		0.8		hardened in mixer
6/28/06 10:00	6/28/06 13:06	0.129	3.1			3.1	Cleaning out mixer
6/28/06 13:06	6/28/06 18:05	0.208	5.0		5.0		Crater repair operation resumed until completion
6/28/06 19:30							2-hr Baseline HWD testing

CRATER 5 - DEGUSSA BUILDING PRODUCTS, 10-61 RAPID REPAIR MORTAR							
			TOTAL HOURS	**PREP HOURS**	**REPAIR HOURS**	**NON-REPAIR HOURS**	
Adjusted hours for repair			**9.4**	**8.5**	**0.9**		
Total hours			**17**	**8.5**	**0.9**	**7.7**	
Start	**End**	**DAY**					**ACTIVITY**
			1.0	1.0			Prior to 23JUN - Set forms
6/23/06 6:55	6/23/06 7:47	0.036	0.9		0.9		START - Pre-wet base layer / position mixer and water truck / mix evaporation reducer and curing compound / position materials
6/23/06 7:47	6/23/06 8:20	0.023	0.5			0.5	Load water and stone into mixer - mixer shaft would not turn
6/23/06 8:20	6/23/06 15:30	0.299	7.2			7.2	REPAIR SUSPENDED to acquire smaller stone and conduct trial batches
6/24/06 8:00	6/24/06 15:30	0.313	7.5	7.5			Crater repair from the first batch mixed and placed in Northwest quadrant to the last mix to complete the repair, and finishing
6/24/06 17:30							2-hr Baseline HWD testing

CRATER 6 - CTS CEMENT, RAPID SET DOT CEMENT							
			TOTAL HOURS	PREP HOURS	REPAIR HOURS	NON-REPAIR HOURS	
Adjusted hours for repair			**7.7**	**3.7**	**4.0**		
Total hours			**9**	**3.7**	**4.0**	**0.9**	
Start	**End**	**DAY**					**ACTIVITY**
			1.0	1			Prior to 21JUN - Cut and set forms
6/21/06 14:40	6/21/06 17:20	0.111	2.7	**2.7**			Calibrate proportional mixer
6/22/06 9:30	6/22/06 10:33	0.044	1.0		1.0		START - Pre-wet base layer / load materials into mixer / position mixer for material placement
6/22/06 10:43	6/22/06 12:25	0.071	1.7		1.7		Southwest and Northeastern quadrants completed / moist cure the slabs
6/22/06 12:25	6/22/06 13:20	0.038	0.9			0.9	Wait until SW and NE slabs have cured / remove formwork
6/22/06 13:20	6/22/06 13:53	0.023	0.6		0.6		Repair Northwest quadrant
6/22/06 14:01	6/22/06 14:44	0.030	0.7		0.7		Re-load mixer with materials
6/22/06 14:44	6/22/06 14:45	0.001	0.0		0.0		Complete Northwest quadrant / position mixer at Southeastern quadrant / complete repair END
6/22/06 16:45							2-hr Baseline HWD testing

An average of 8 hr was needed to repair a large crater using RS materials. An overall comparison of the adjusted total time required to complete the crater repairs ranges from 7.7 to 10 hr. The repair requiring the least amount of time was Crater 6, CTS Cement, DOT Rapid Set at just under 8 hr, while Crater 2, CeraTech, Pavemend EX-H required the most amount of time at 10 hr. Between these times was Crater 4, Ultimax Concrete at 8.5 hr, Crater 5, Degussa Thoroc 10-61 Repair Mortar at 9.4 hr. The repair time for Crater 1, stone and grout was 7.4 hr. Caution must be used when comparing these repair times. Unlike the craters repaired using the portable 2 yd^3 mixer, Crater 6 utilized a larger (6 yd^3) volumetric mixer. A factor contributing to the repair time for Crater 6 was that the volumetric mixer was operated by proficient and specially trained operators.

A comparison of the manpower requirements are given in Table 17. The primary team member duties and crew size are listed. A team size of 16 was used to repair Craters 1, 5, and 6, while a team of 12 was used to repair Craters 2 and 4. Typically, 2 equipment operators were needed continually for the multi-terrain loader and forklift to handle the materials and position the equipment and successive batches. For the mixing operation, 4 were needed – 2 on the mixer to assist adding mix water, loading the rapid setting material, and observing the mixer operation, and 2 others on the ground, one with the water truck to monitor the quantity of water going into the mixer, the other assisting with running the mixer and repositioning the mixer). The remaining team members were needed to spread and finish the material once it was in the crater. The use of the volumetric mixer for Crater 6, with the specially trained operators, decreased the need for remaining team members to spread and finish the RS material in the crater.

Table 17. Comparison of manpower requirements to repair each crater.

	CRATER				
	1	**2**	**4**	**5**	**6**
Crew Size	**16**	**12**	**12**	**16**	**16**
Mixing		4	4	6	3*
Material Handling		2	1	2	2
Spreading concrete & Finishing		6	7	8	5

* Equipment owner and Zimmerman representatives

Table 18 considers the materials and water requirements to complete the crater repairs. The notion of an all-inclusive mix, such as Ultimax Concrete, has the appeal of only needing water to complete the mix, as opposed to the other RS materials requiring material to extend the mixes. A disadvantage for this material is additional weight, as these Ultimax Concrete supersacks were the heaviest at 3,000 lb each – a drawback for valuable air transport capacity. In contrast, the CTS Cement Rapid Set DOT Cement used the least amount of RS material, but was extended with both fine and coarse aggregates from stockpiles on site. High quality materials may not be available in theater and the effects on this material are unknown. It is clear that a change in the mix would prompt the need to recalibrate the volumetric mixer to ensure proper proportioning of the mix. Both the Degussa ThoRoc 10-61 and CeraTech Pavemend EX-H were extended with the #89 stone, a smaller stone than originally planned, and mixed reasonably well in the 2 yd^3 portable mixer.

The availability of potable water is a significant issue, not only for mixing the RS material, but also for cleaning out and maintaining the mixing equipment. Table 18 compares the materials and water requirements for each material. The Ultimax Concrete material was an all-inclusive mix and only required mix water. This material also used the highest quantity of water per supersack for mixing. All of the materials recommend pre-wetting the base layer prior to placing the materials. While, from a practical sense, this helps to reduce the temperature of the underlying layer, and reduces the loss of free water needed for RS material hydration, it also creates an extra requirement for water.

Table 18. Comparison of material and water requirements.

	CRATER				
	1	2	4	5	6
Material	**Standard bag Type I cement**	**Supersack**	**Supersack**	**Supersack**	**Supersack**
Weight (each)	94-lb bags	2,000-lb	3,000-lb	2,500-lb	2,000-lb
Rapid setting material used		27 (of 29)	29 (of 30)	21 (of 22)	7 (of 10)
Materials to extend	#4 rock	#89 stone	(Not needed - all inclusive mix)	#89 stone	#57 aggregate concrete sand
Admixtures	Calcium chloride (accelerator)	None used	None used	None used	Citric acid (retarder)
Mix water	120 gal per $yard^3$	31 - 34 gal per sack	50 gal per sack	30 - 41 gal per sack	11.2 ga/min
Additional water to pre-wet base layer		Yes - 30-50 gal	Yes - 100 gal	Yes - 30-50 gal	Yes - 30-50 gal

6 Dynamic Load Tests

Following each crater repair, there was a brief 4 hr curing period prior to trafficking. An initial 100 passes was applied to each crater individually using a load cart equipped with an F-15E tire. Once all of the crater repairs had been completed the remaining passes were applied. Craters 1 and 2 were trafficked simultaneously and Craters 4, 5, and 6 were trafficked together, bypassing Crater 3, due to the surface roughness. The target number of passes for the repaired craters was 5,000. At specific intervals during the trafficking, performance data was collected to monitor slab movement, structural performance, seismic modulus, and the surface condition. Measurements were made using rod and level surveys, heavy weight deflectometer (HWD), portable seismic pavement analyzer (PSPA), static and dynamic load response, and pavement condition surveys. The series of tests is summarized in Table 19.

Table 19. Summary of interval performance data collected during dynamic load testing.

Pass Number(s)	Time	Patterns	Coverages	Dynamic Response Data[A]	Static Response Data	Rod & Level Cross sections Profile[B]	HWD	PSPA	Pavment Condition Survey [C]
0	0	0	0	------	------	X	X	X	X
0	2 hr	0	0	------	------	------	X	X	------
0	4 hr	0	0	------	------	------	X	X	------
	Following morning - Cool	------	------	------	------	------	X	X	------
	Following afternoon - Hot	------	------	------	------	------	X	X	------
	7-day morning	------	------	------	------	------	X	X	------
	7-day afternoon	------	------	------	------	------	X	X	------
	14-day morning	------	------	------	------	------	X	X	------
	14-day afternoon	------	------	------	------	------	X	X	------
1-112		------	------	X	------	------	------	------	------
102		7	25.5	------	X	X	X	X	X
497-528		------	------	X	------	------	------	------	------
510		32	127.5	------	X	X	X	X	X
993-1,008		------	------	X	------	------	------	------	------
1,013		63	253.25	------	X	X	X	X	X
1,985-2,016		------	------	X	------	------	------	------	------
1,995		125	498.75	------	X	X	X	X	X
4,977-5,008		------	------	X	------	------	------	------	------
5,006		313	1,251.5	------	X	X	X	X	X

[A] Additional dynamic data collected if cap deteriorates under traffic.
[B] Monitor crater repair and collect additional data as needed, especially between 0 and 112 passes.
[C] Monitor each pass from 1 to 112. Perform condition survey and highlight cracks for photos at designated intervals. Collect additional data if cap deteriorates under traffic.

The AFRL load cart was used to traffic the repaired craters. It consisted of a front end loader connected to a flat cart stacked with lead weights (Figure 102). The F-15E tire was loaded to 35,200 lb with a tire pressure of 325 psi. The load cart was manually operated by driving forward and backward along the painted traffic lanes. A modified F-15E traffic pattern (Figure 103) was used that consisted of 5 lanes, each 9 in wide, to simulate

wander. A single F-15E pattern consisted of 16 passes of the load cart. Odd numbered passes identify traffic applied in the forward direction; even numbered passes are passes applied in the reverse direction. The pass to coverage ratio for the modified F-15E pattern is 4.

Figure 102. Photograph of F-15E load cart.

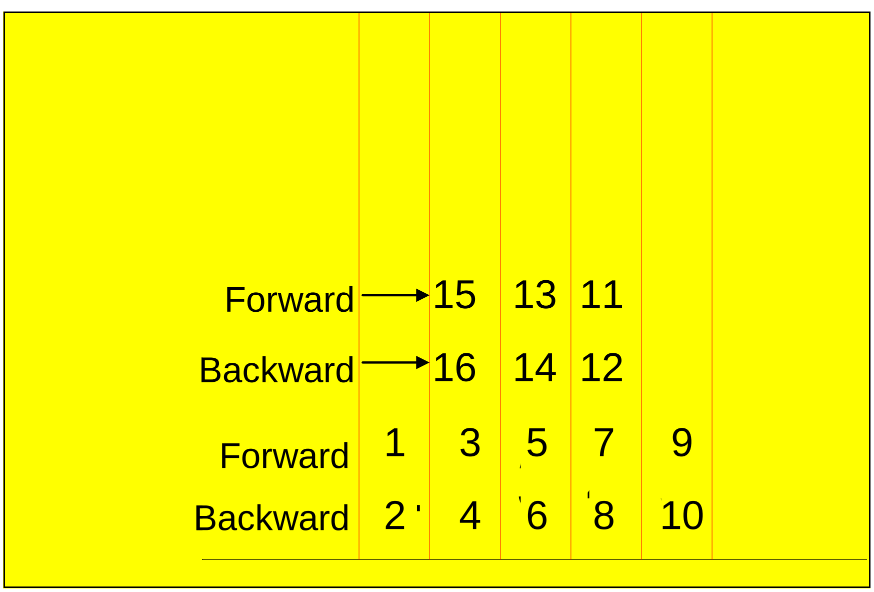


Figure 103. Modified F-15 traffic pattern.

During each crater repair, cylinders were cast by ERDC personnel and tested by AFRL material laboratory personnel for compressive strength. At the completion of all trafficking, cores were removed by AFCESA for splitting tensile tests conducted at the AFRL test laboratory. The test results are included in this section.

Performance data

Rod and level surveys.

At each test interval, rod and level survey measurements were collected at 1 ft spacing along the profile of the traffic lane and at 3 cross section locations across the repair (Figure 104). Current criteria require that the final surface of an airfield repair be flush with the existing undamaged pavement, within a tolerance of ± ¾ in (Air Force 2008a). Figure 105 to Figure 109 present the surface measurements collected during each interval for each crater. The figures also show the accepted tolerance of ± ¾ in as the dashed line. Prior to the repairs, survey measurements were collected after placing the base material. The thickness of the RS cap is also shown in the figures. Figure 106 illustrates the 2 in of aggregate pre-placed before the RS material in Crater 2, resulting in repair cap thickness ranging from 6 to 8 in.

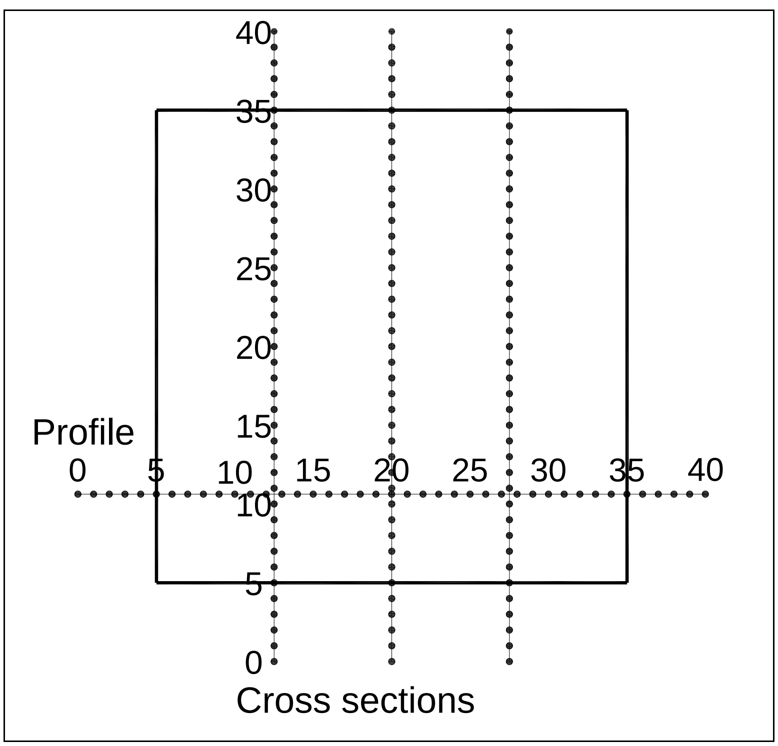


Figure 104. Layout of profile and cross section measurement points for rod and level survey.

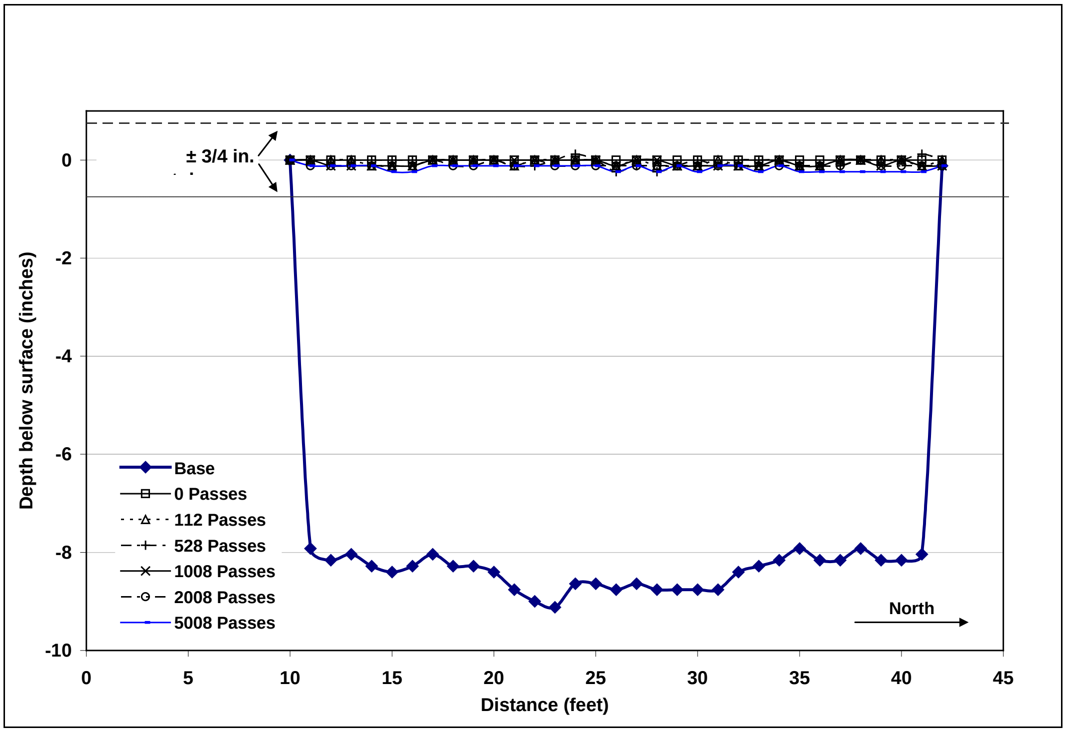


Figure 105. Crater 1 profile survey of traffic lane throughout testing period.

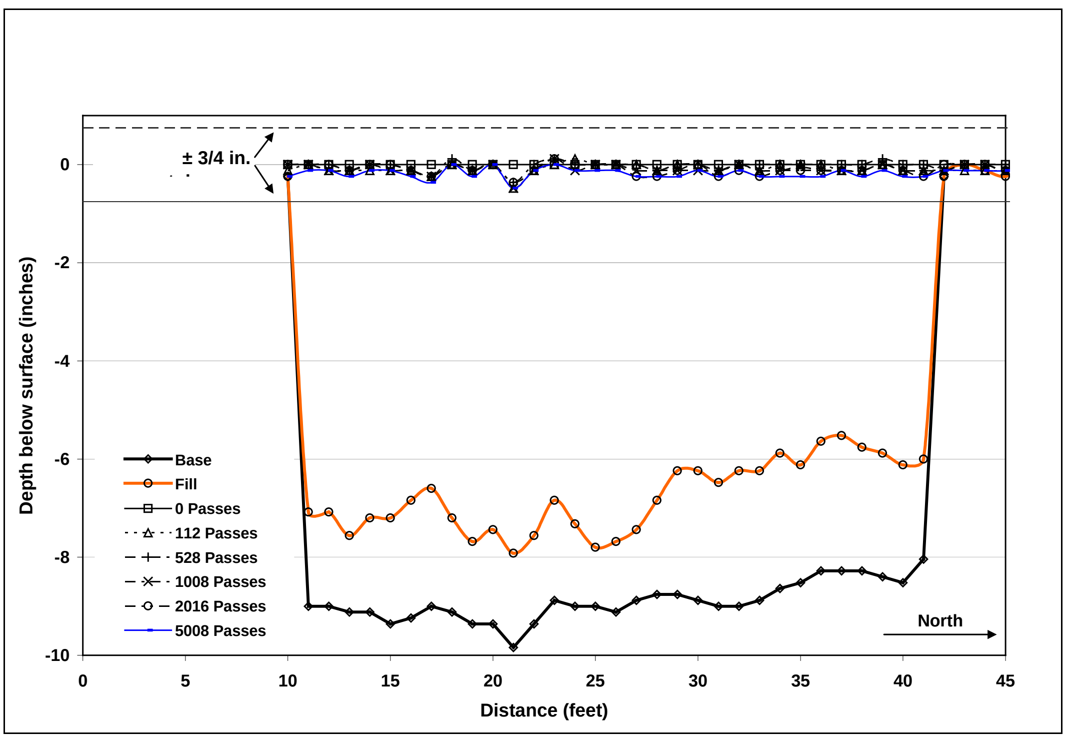


Figure 106. Crater 2 profile survey of traffic lane throughout testing period.

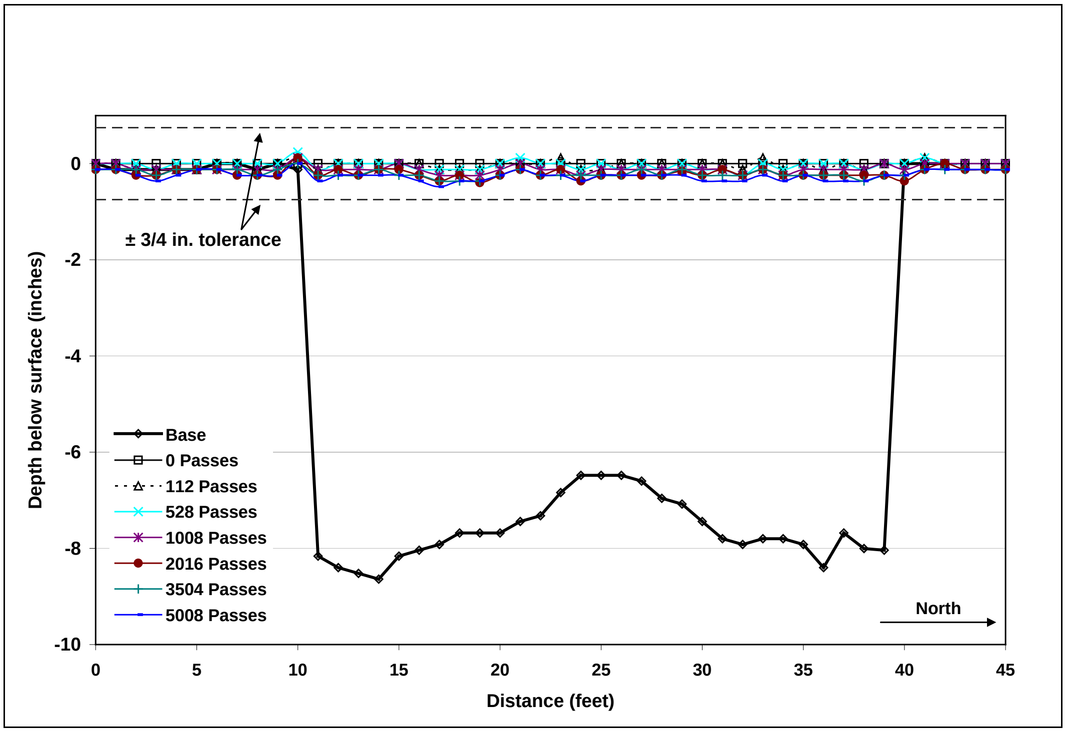


Figure 107. Crater 4 profile survey of traffic lane throughout testing period.

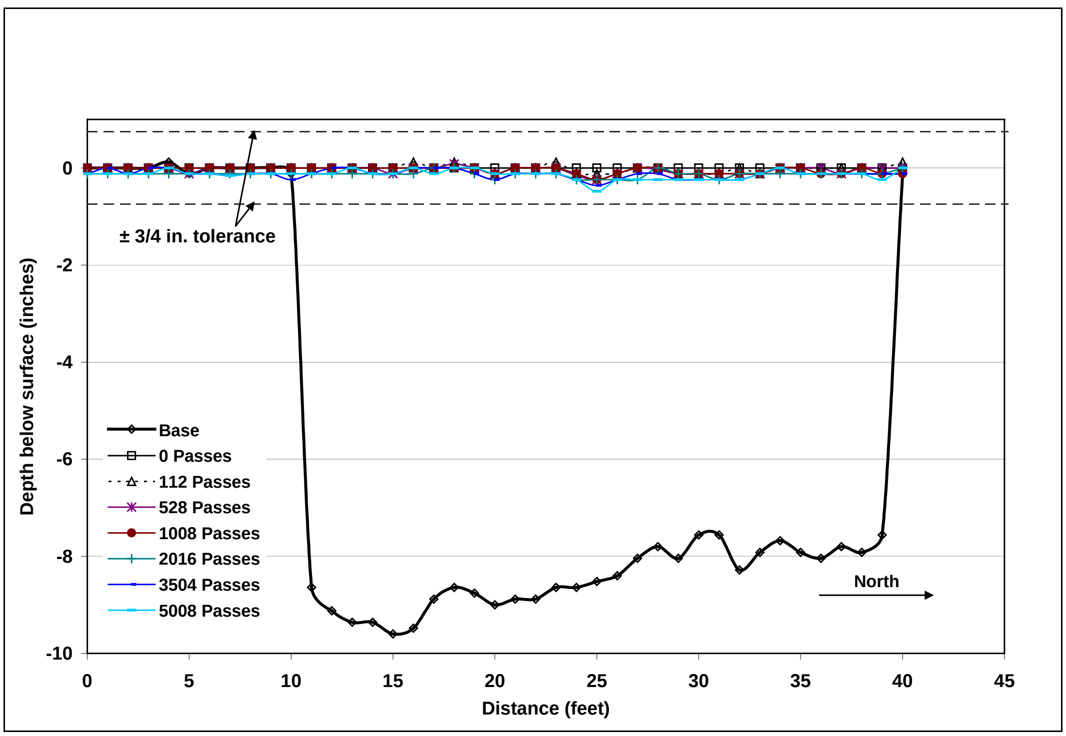


Figure 108. Crater 5 profile survey of traffic lane throughout testing period.

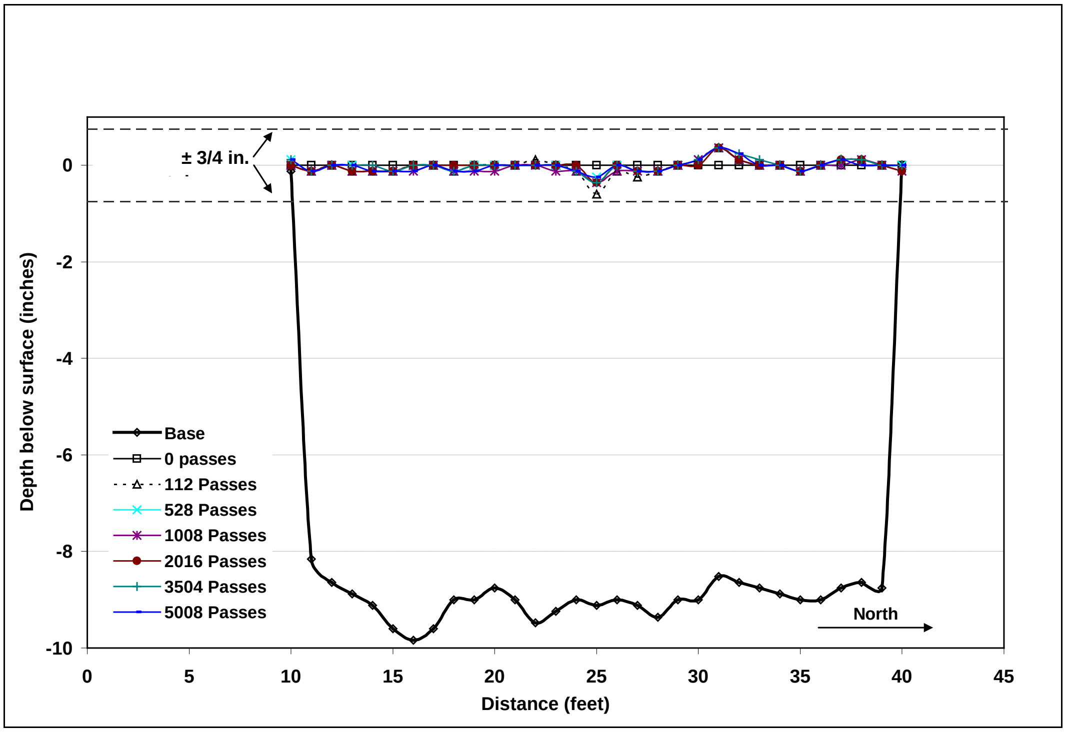


Figure 109. Crater 6 profile survey of traffic lane throughout testing period.

HWD data.

There were a total of four HWD test points on each test crater. Three of the test points were located in the traffic lane: one over each of the two pressure cells in the southeastern quadrant, and one test point at the center of the northeastern quadrant. The fourth test point was located in the center of a non-trafficked quadrant. The HWD test protocol consisted of six drops, the first three were the highest load range of 57 kips and with each successive drop, the load decreased (40, 30, and 20 kips).

HWD data was used to monitor the structural performance of the repair. The deflection reading at the first geophone (under the center of the plate) should not exceed 80 mils. To compare the test results, the readings were normalized to a common load of 60 kips and plotted. Figure 110 to Figure 124 show a series of deflection basins for three of the test points for each crater: over the pressure cell near the edge in the southeastern quadrant, over the pressure cell at the center of the southeastern quadrant, and a third point on the non-trafficked side of the repair.

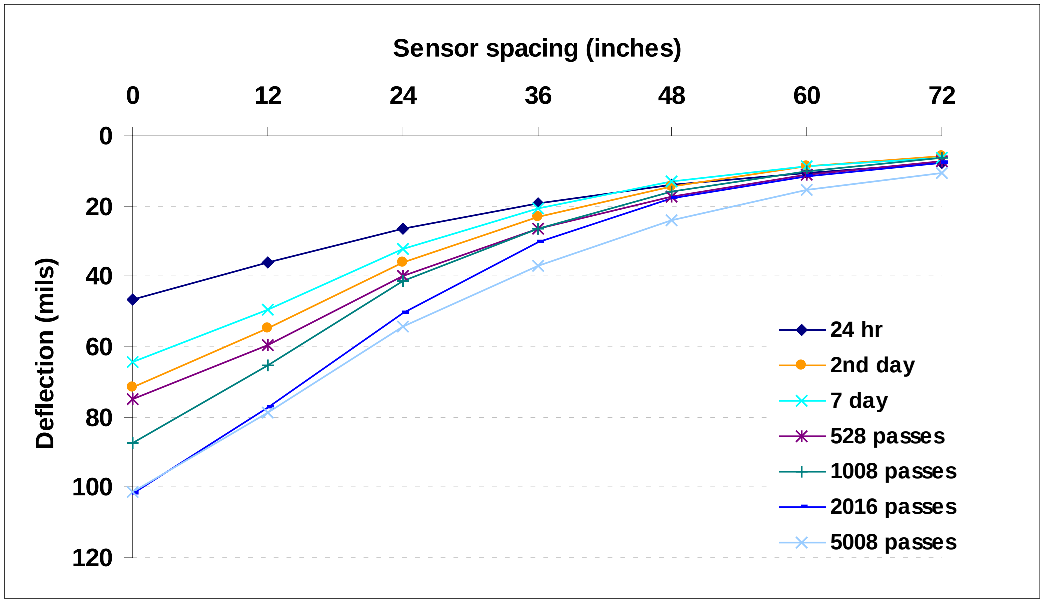


Figure 110. Normalized deflection readings over edge pressure gage for Crater 1 throughout testing period.

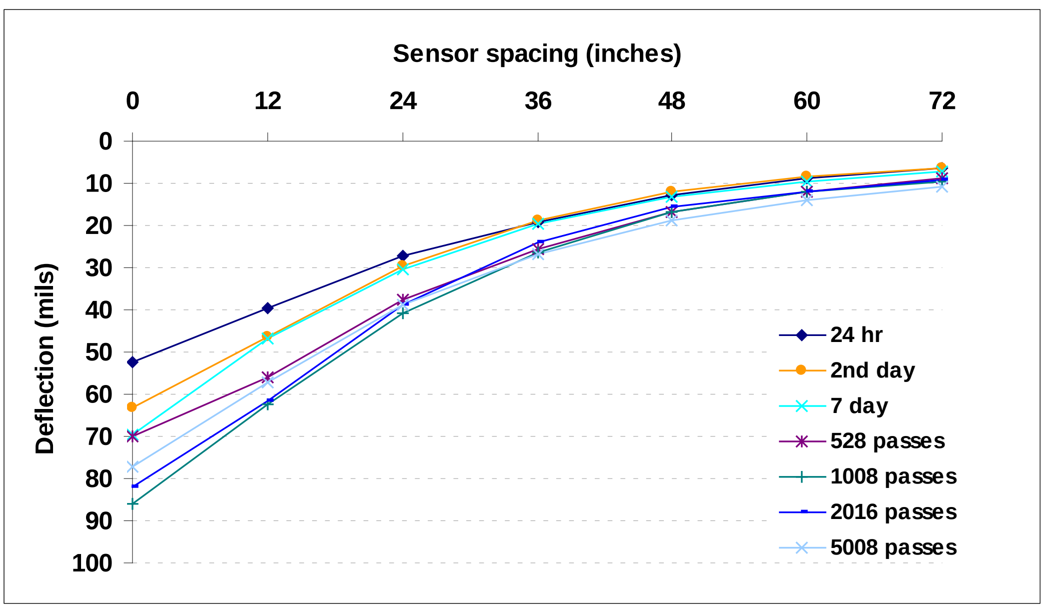


Figure 111. Normalized deflection readings over center pressure gage for Crater 1 throughout testing period.

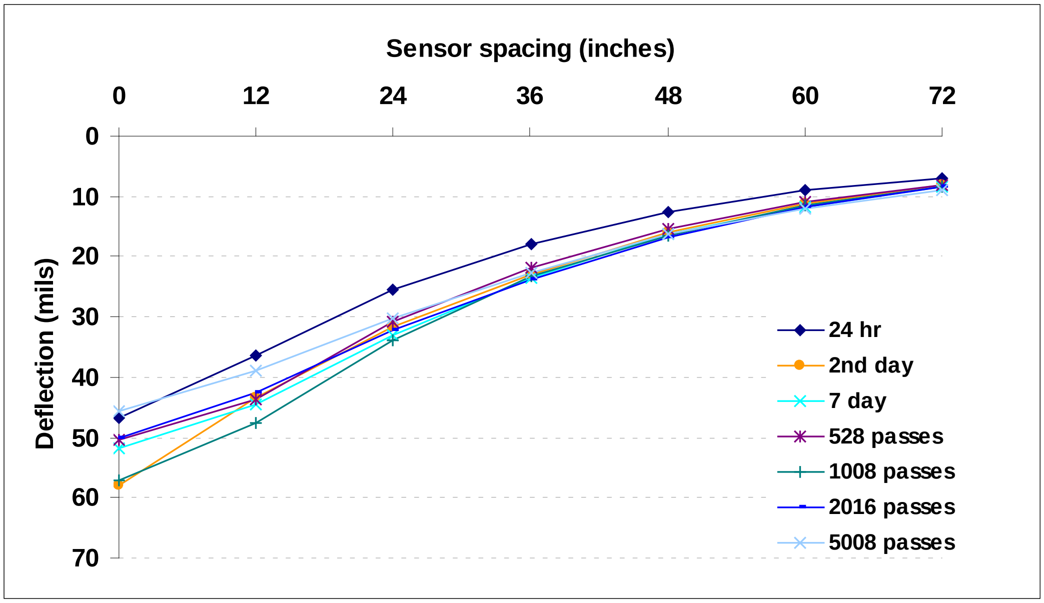


Figure 112. Normalized deflection readings in non-trafficked section of repair for Crater 1 throughout testing period.

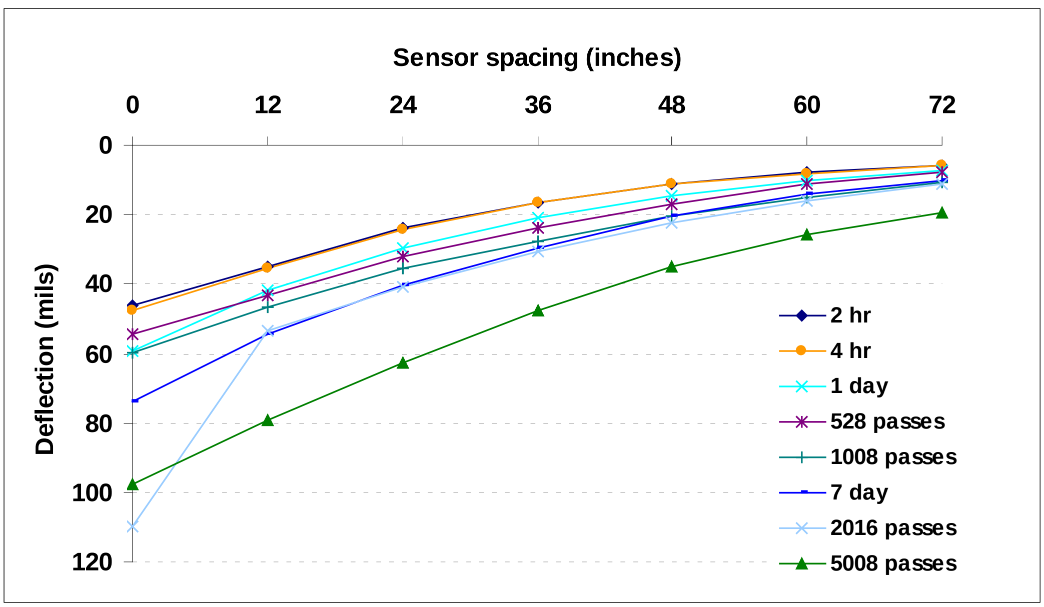


Figure 113. Normalized deflection readings over edge pressure gage for Crater 2 throughout testing period.

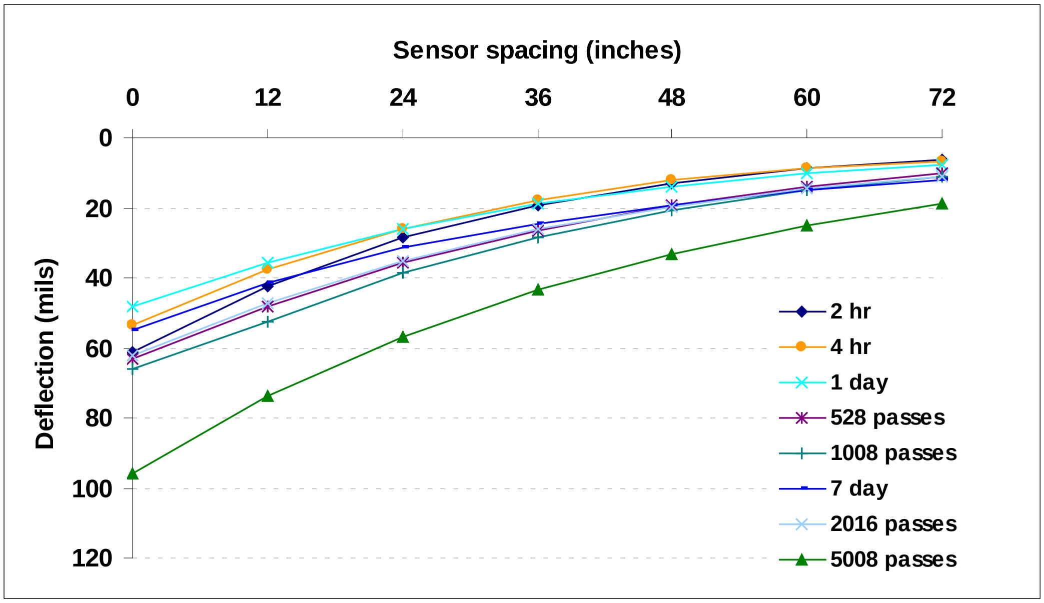


Figure 114. Normalized deflection readings over center pressure gage for Crater 2 throughout testing period.

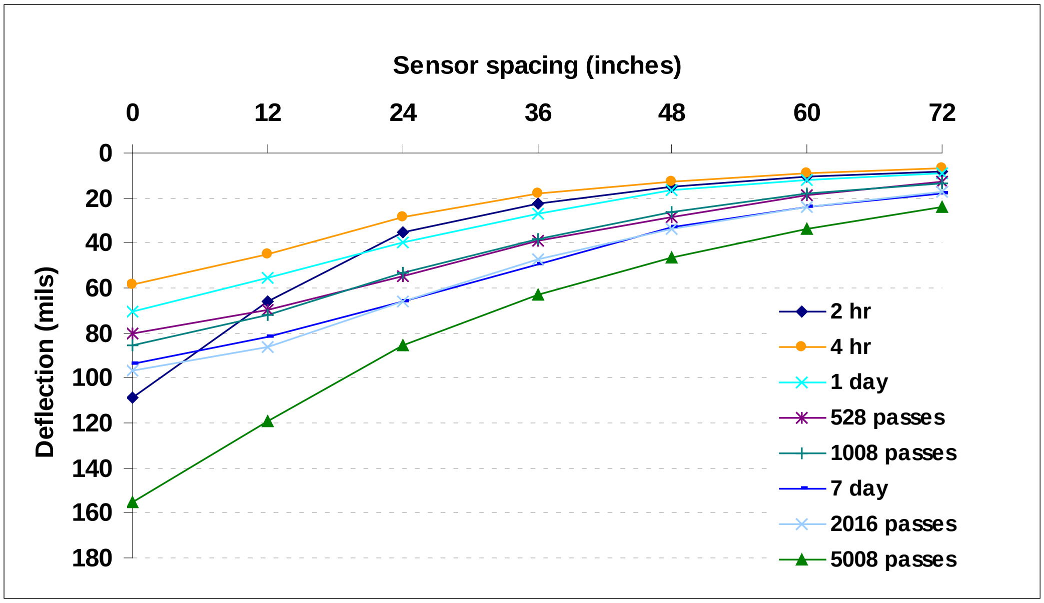


Figure 115. Normalized deflection readings in non-trafficked section of repair for Crater 2 throughout testing period.

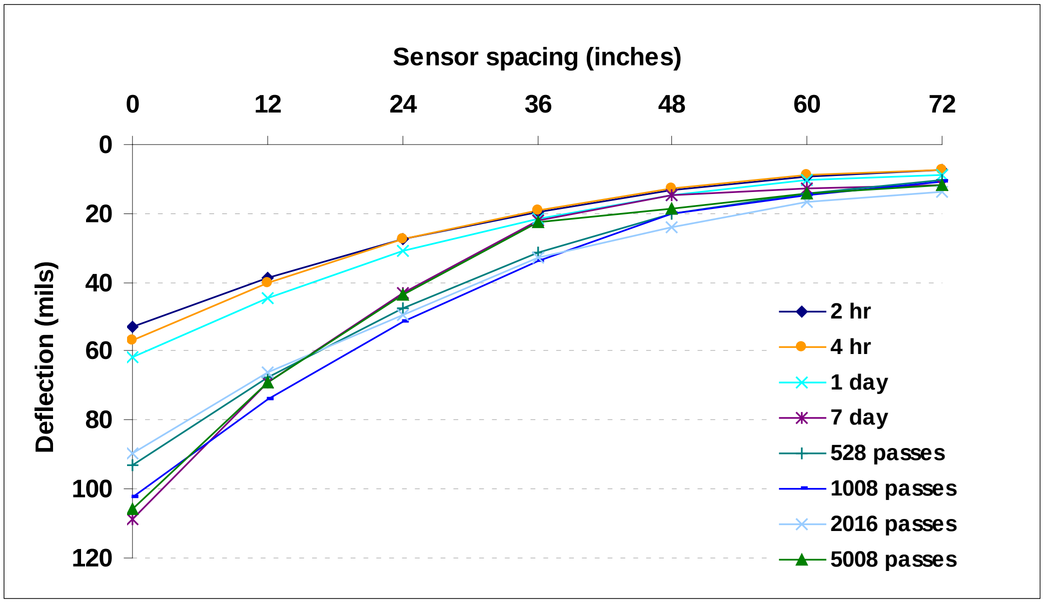


Figure 116. Normalized deflection readings over edge pressure gage for Crater 4 throughout testing period.

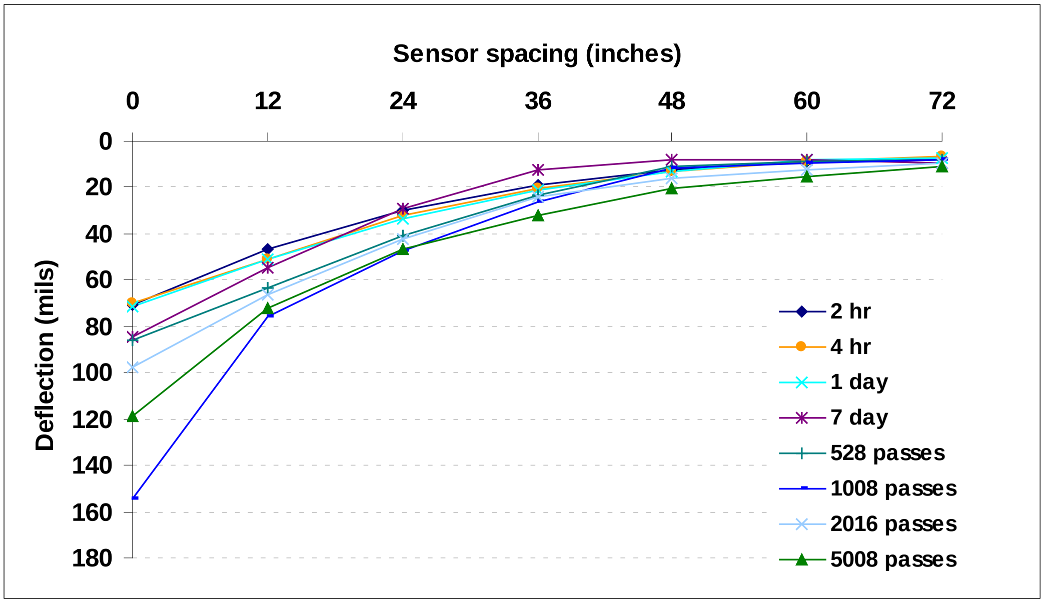


Figure 117. Normalized deflection readings over center pressure gage for Crater 4 throughout testing period.

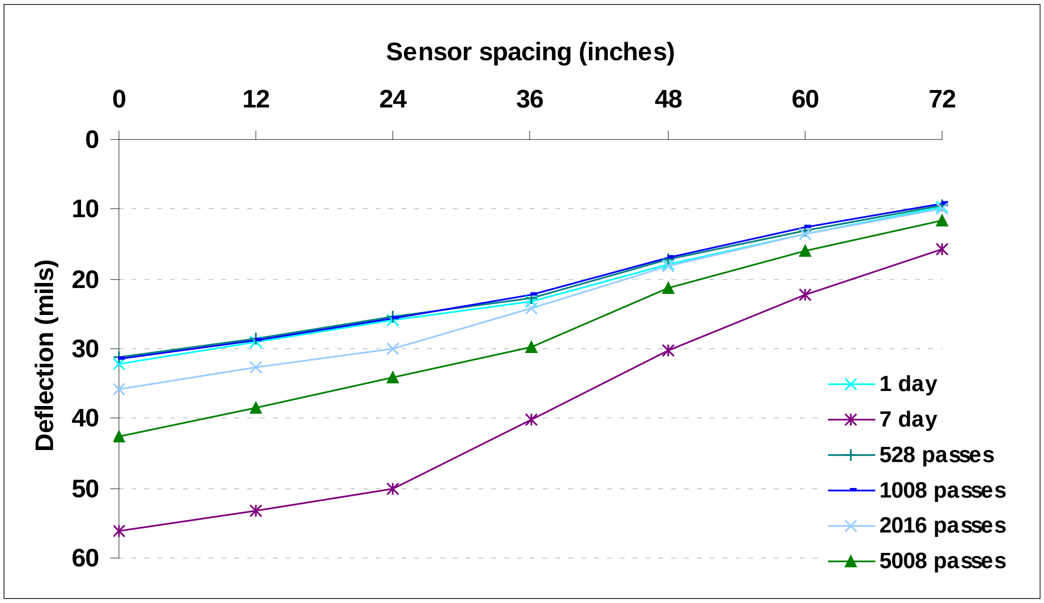


Figure 118. Normalized deflection readings in non-trafficked section of repair for Crater 4 throughout testing period.

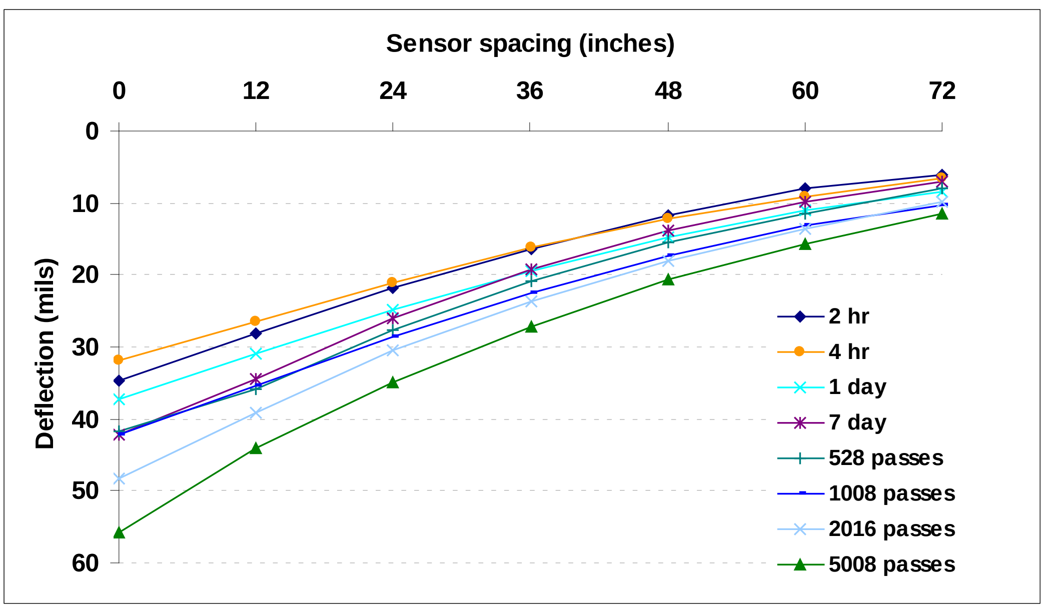


Figure 119. Normalized deflection readings over edge pressure gage for Crater 5 throughout testing period.

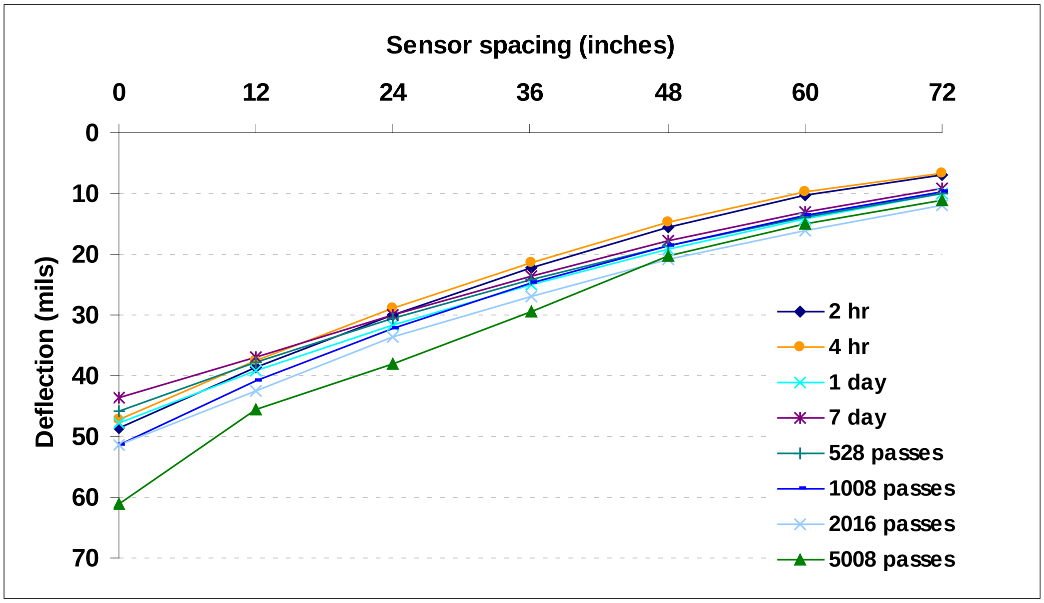


Figure 120. Normalized deflection readings over center pressure gage for Crater 5 throughout testing period.

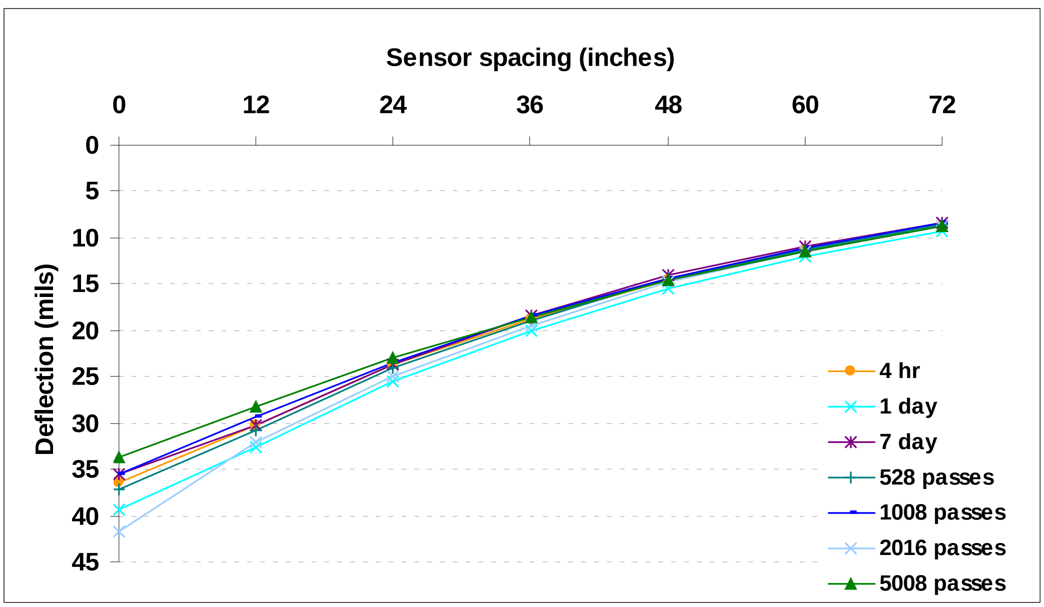


Figure 121. Normalized deflection readings in non-trafficked section of repair for Crater 5 throughout testing period.

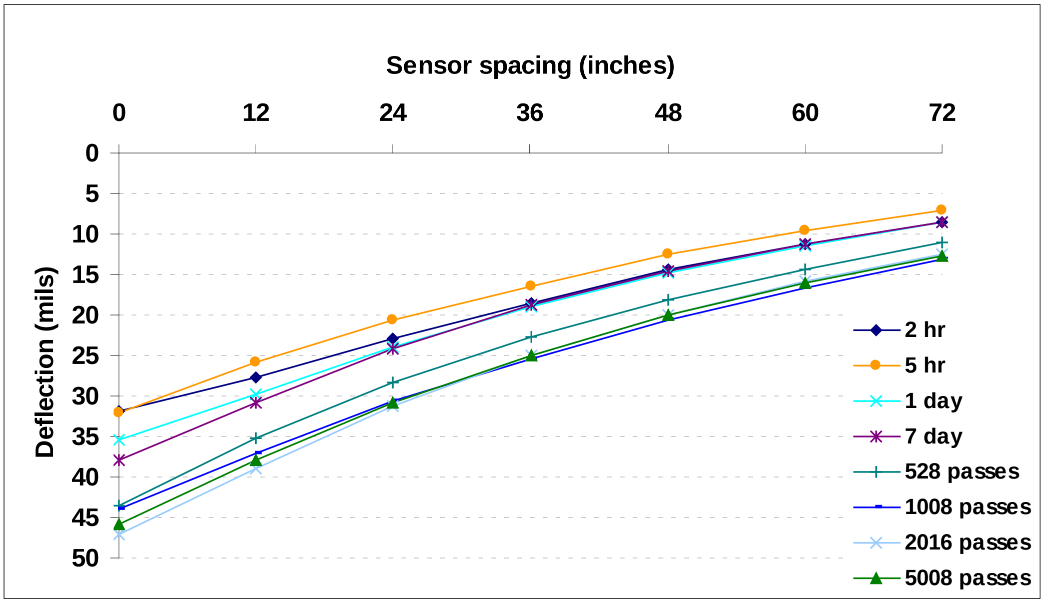


Figure 122. Normalized deflection readings over edge pressure gage for Crater 6 throughout testing period.

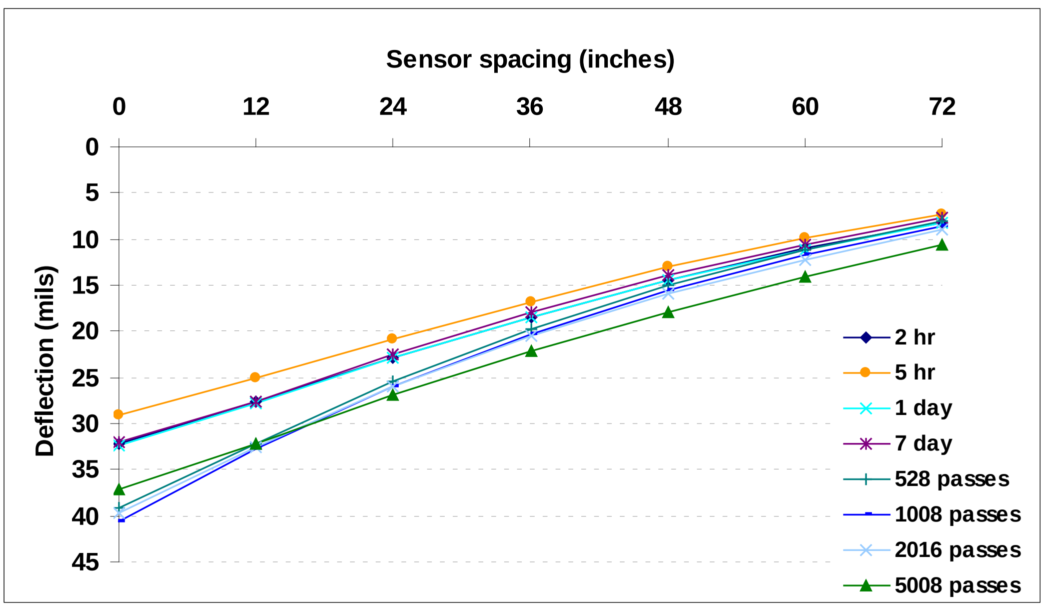


Figure 123. Normalized deflection readings over center pressure gage for Crater 6 throughout testing period.

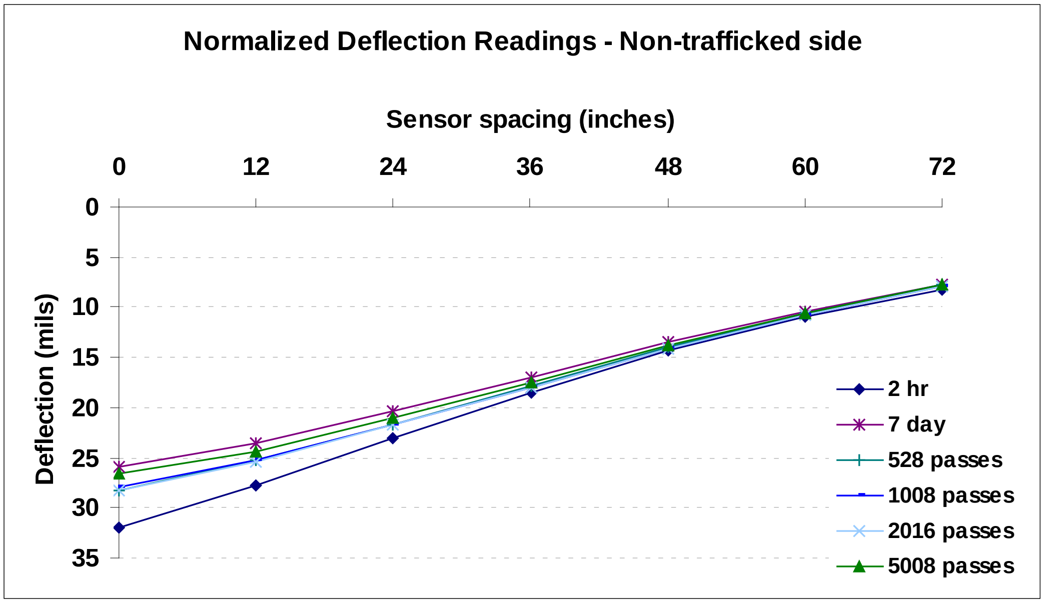


Figure 124. Normalized deflection readings in non-trafficked section of repair for Crater 6 throughout testing period.

PSPA data to estimate Young's modulus.

After HWD testing, measurements were made of the in-situ seismic modulus of the RS materials using the portable seismic pavement analyzer (PSPA) (Bell 2006). The PSPA generates ultrasonic surface waves from the source rod that are sensed by the receivers. The PSPA device is portable and nondestructive allowing for numerous, rapid readings of the Young's modulus. There were a total of four PSPA test points. The two of interest for this test were located near the two HWD test points (over the pressure gages; SE gage at the edge, and CL gage in the center) in the southeastern quadrant. A minimum of three readings were taken at each test point and averaged. One issue that came up during trafficking was taking readings as cracks formed in the repairs. In such instances, the modulus readings were beyond a reasonable value and testing at that point was repeated. Table 20 summarizes the average readings with increasing pass level for each crater near the pressure cell locations. The modulus values from the PSPA are compared with the modulus values determined in the laboratory (Figure 125 to Figure 129). The recommendation from the ETL for testing rigid spall repair material (U.S. Air Force 2008b), indicated on the plots as the dashed line, is a modulus value not to exceed $4\text{x}10^6$ psi after 72 hours.

Table 20. PSPA modulus values and calculated flexural strengths compared to laboratory testing values.

				Edge Pressure Gage		Center Pressure Gage		Laboratory Values							
	Age (hours)	Date	Pass Level	Average Modulus (ksi)	Calculated Flexural Strength (psi)	Average Modulus (ksi)	Calculated Flexural Strength (psi)	Age (hours)	Ambient Modulus (ksi)	Age (hours)	Elevated Modulus (ksi)	Age (hours)	Ambient Flexural (psi)	Age (hours)	Elevated Flexural (psi)
Crater 1	20	6/21/06	0	2,780	334	4,848	582								
	40	6/22/06	112	3,718	446	3,176	381								
	239	6/30/06	528	4,940	593	6,961	835								
	306	7/3/06	1008	4,743	569	7,315	878								
	329	7/4/06	2016	6,651	798	6,641	797								
	420	7/8/06	3586	6,327	759	4,047	486								
	469	7/10/06	4200	5,656	679	4,425	531								
	492	7/11/06	5008	5,003	600	3,854	463								
	157	6/27/06	7 day	4,302	516	3,658	439								
Crater 2	2	6/27/06	0	2,460	295	2,593	311	2		2	350	2		2	83
	4	6/27/06	0	2,654	318	2,804	336	6	150	6	1,717	6		6	228
	14	6/28/06	112	3,153	378	3,097	372	24	2,783	24	3,125	24	118	24	358
	73	6/30/06	528	3,584	430	3,576	429	672	3,800	672	5,090	672	268	672	555
	140	7/3/06	1008	3,628	435	3,110	373								
	163	7/4/06	2016	3,358	403	2,613	314								
	254	7/8/06	3586	6,428	771	4,060	487								
	303	7/10/06	5008	3,668	440	4,479	538								
	158	7/4/06	7 day	5,270	632	3,687	442								
Crater 4	2	6/28/06	0	3,093	371	2,958	355	2				2			
	4	6/28/06	0	3,247	390	3,123	375	6	2,700			6	95		
	16	6/29/06	112	3,330	400	3,616	434	24	3,717			24	265		
	67	7/1/06	528	2,338	281	3,607	433	672	4,550			672	658		
	116	7/3/06	1008	3,697	444	3,875	465								
	163	7/5/06	2016	2,966	356	3,669	440								
	232	7/8/06	3504	3,839	461	3,535	424								
	331	7/12/06	5008	4,774	573	4,334	520								
	158	7/5/06	7 day	3,597	432	4,055	487								
Crater 5	2	6/24/06	0	3,717	446	4,420	530	4	4,167	2	3,300	4	378	2	205
	4	6/24/06	0	4,450	534	4,580	550	6	4,300	6	3,367	6	425	6	345
	26	6/25/06	112	4,054	486	4,269	512	24	4,683	24	3,367	24	543	24	393
	166	7/1/06	528	4,652	558	6,181	742	672	5,933	672	4,383	672	760	672	578
	215	7/3/06	1008	4,011	481	4,663	560								
	262	7/5/06	2016	4,250	510	2,633	316								
	331	7/8/06	3504	4,162	499	3,807	457								
	430	7/12/06	5008	4,769	572	4,915	590								
	160	7/1/06	7 day	3,663	440	5,428	651								
Crater 6	2	6/22/06	0	5,580	670	4,763	572	2	5,517	4	4,250	2	523	3	130
	5	6/22/06	0	5,360	643	4,910	589	6	6,300	6	5,267	6	745	6	503
	25	6/23/06	112	5,600	672	5,380	646	24	7,067	24	5,933	24	815	24	673
	215	7/1/06	528	4,860	583	4,961	595	672	6,725	672	6,433	672	828	672	653
	263	7/3/06	1008	5,000	600	5,330	640								
	311	7/5/06	2016	5,170	620	5,243	629								
	380	7/8/06	3504	5,530	664	4,967	596								
	479	7/12/06	5008	5,190	623	5,103	612								
	163	6/29/06	7 day	5,770	692	4,928	591								

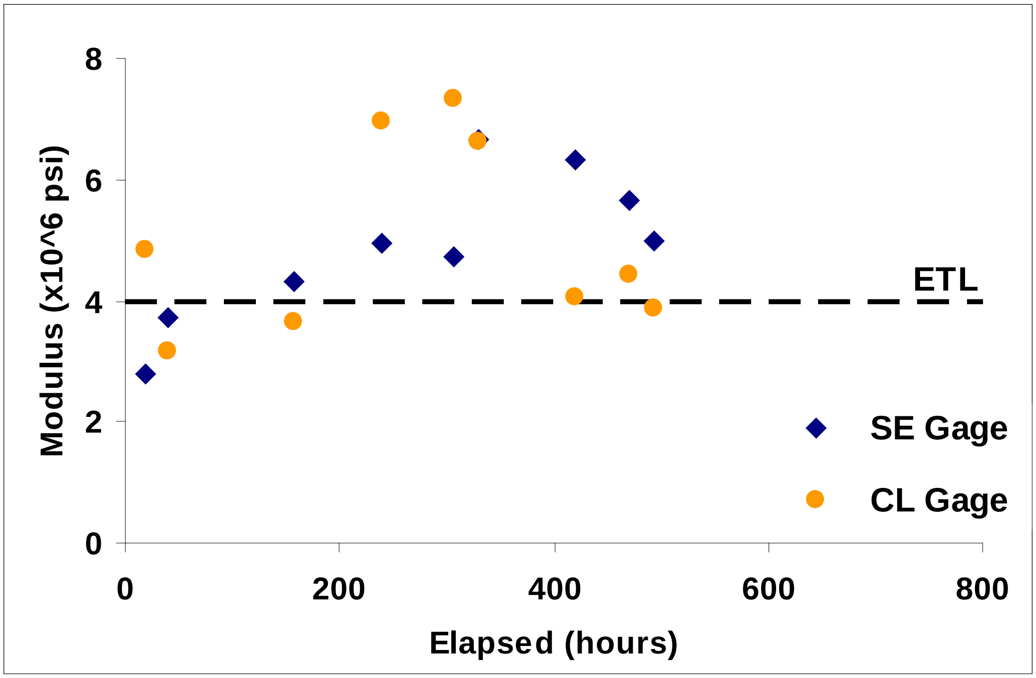


Figure 125. Crater 1, average Young's modulus values throughout testing period.

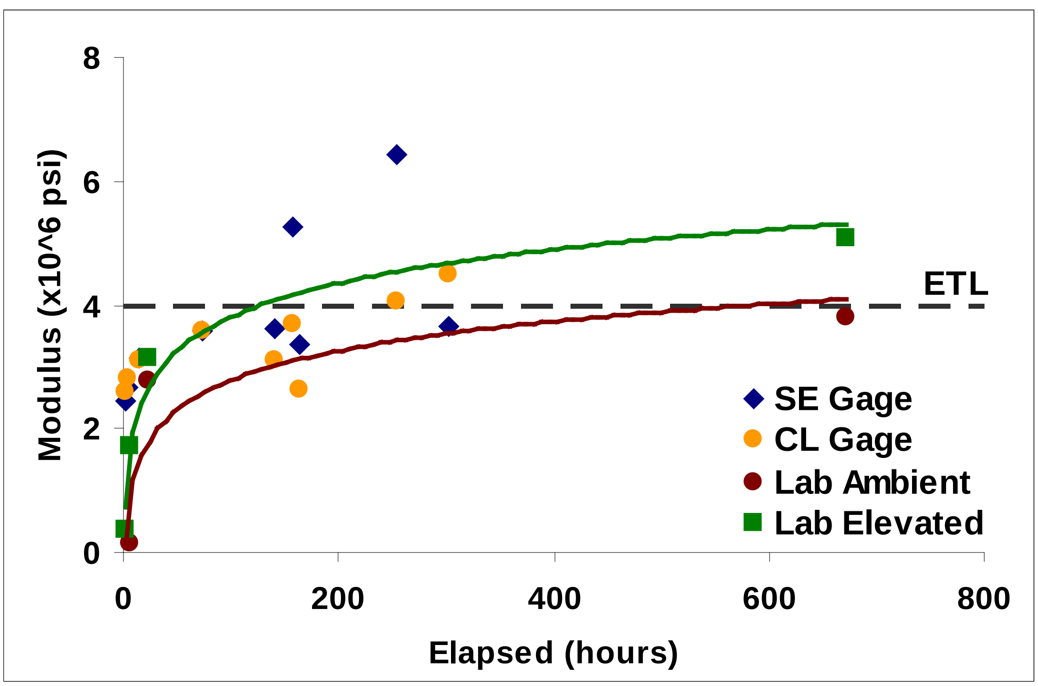


Figure 126. Crater 2, average Young's modulus values compared with test results from laboratory ambient and elevation temperature conditions.

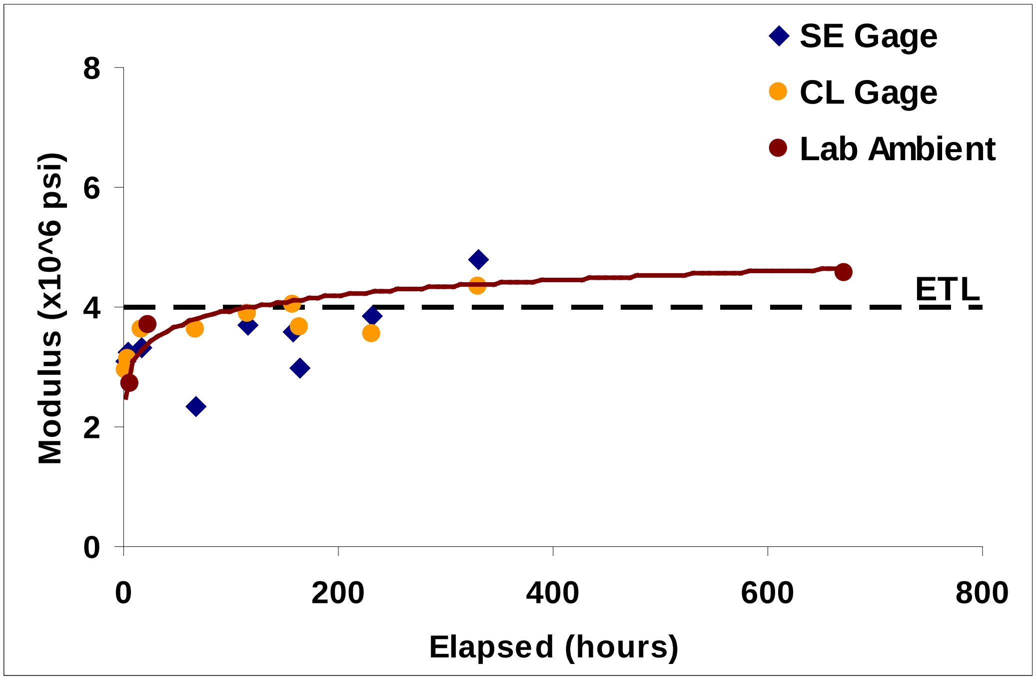


Figure 127. Crater 4, average Young's modulus values compared with test results from ambient laboratory condition.

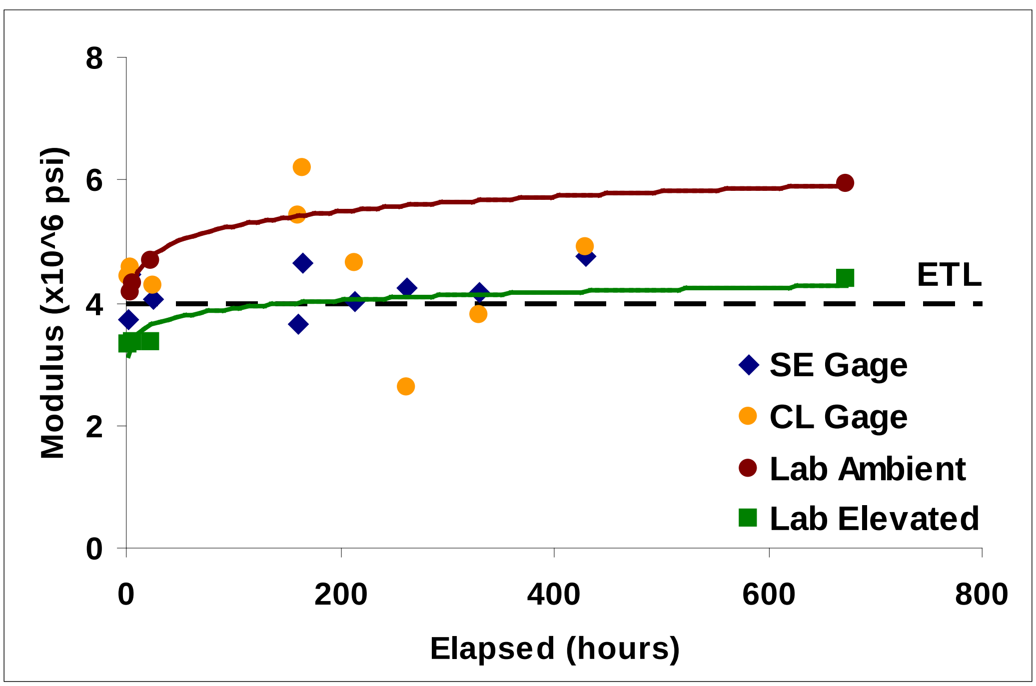


Figure 128. Crater 5, average Young's modulus values compared with test results from ambient and elevated laboratory conditions.

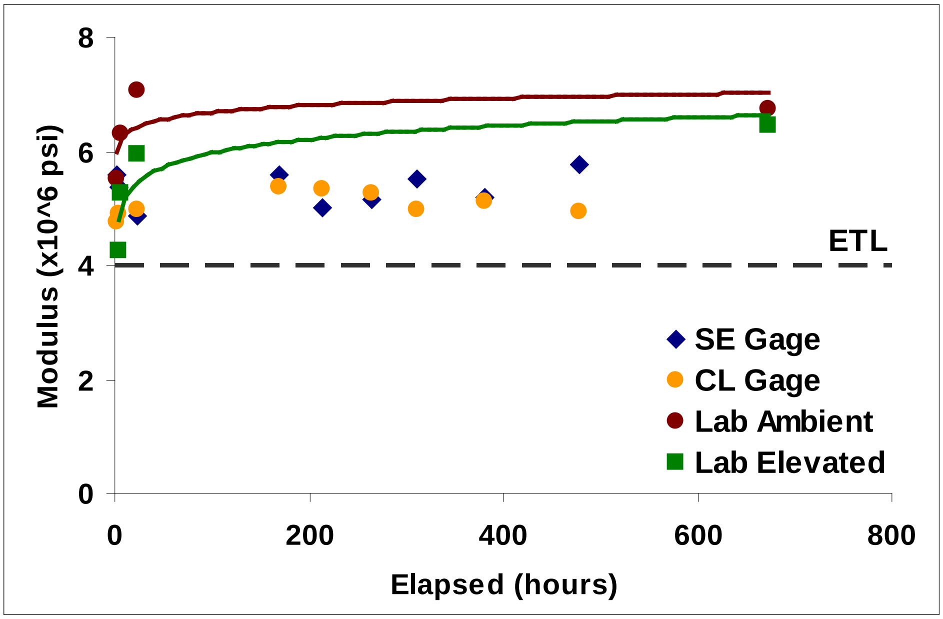


Figure 129. Crater 6, average Young's modulus values compared with test results from ambient and elevated laboratory conditions.

PSPA data to calculate flexural strength.

A relationship has been established using the Young's modulus (E_{PSPA}, ksi) value determined by the PSPA to calculate the flexural strength (Bell 2006).

$$Flexural\_strength = 0.12 * E_{PSPA} \tag{1}$$

The average field modulus value for E_{PSPA} was used to calculated flexural strength using field data, and was compared with the measured values determined in the laboratory (Table 20, and Figure 130 to Figure 134).

Surface condition surveys.

The surface condition was visually assessed and photographed to document the types and severity of the distresses observed during trafficking. The primary distress types monitored were structural and FOD (foreign object damage) for rigid pavements, in accordance with U.S. Air Force Engineering Technical Letter 02-19: Airfield Pavement Evaluation Standards and Procedures (2002). Sizable cracks were painted with orange paint to highlight them for the photographs. In cases where significant fine cracking occurred, such as the extensive shrinkage cracking in Crater 1, a number of cracks were highlighted with orange paint in order to show the significant extent of the cracking.

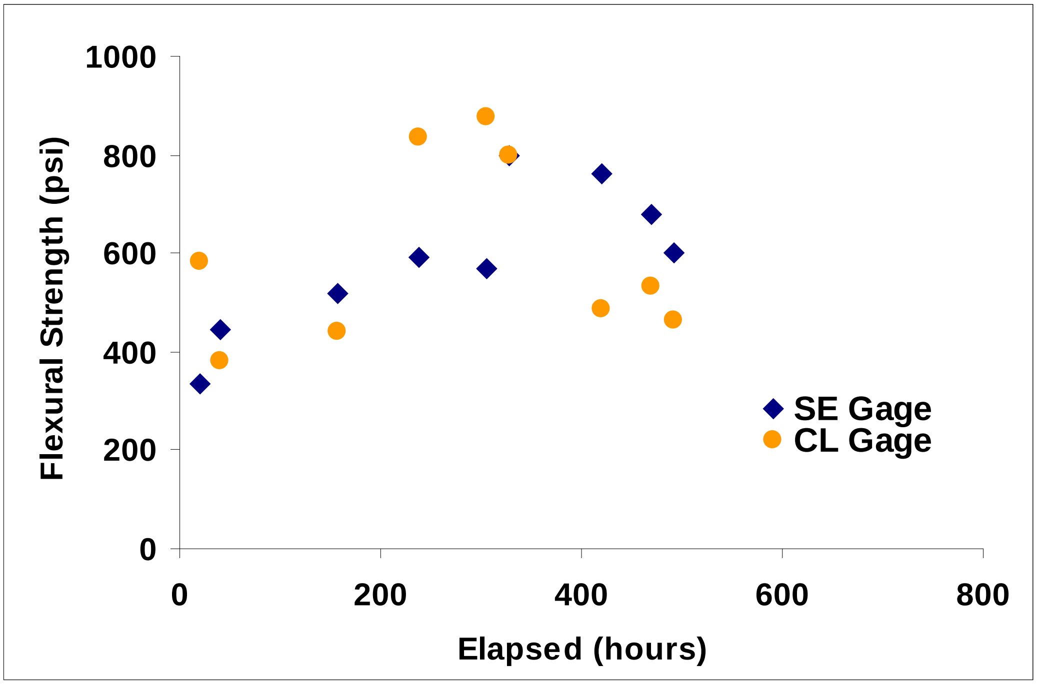


Figure 130. Crater 1, average calculated flexural strength during testing period.

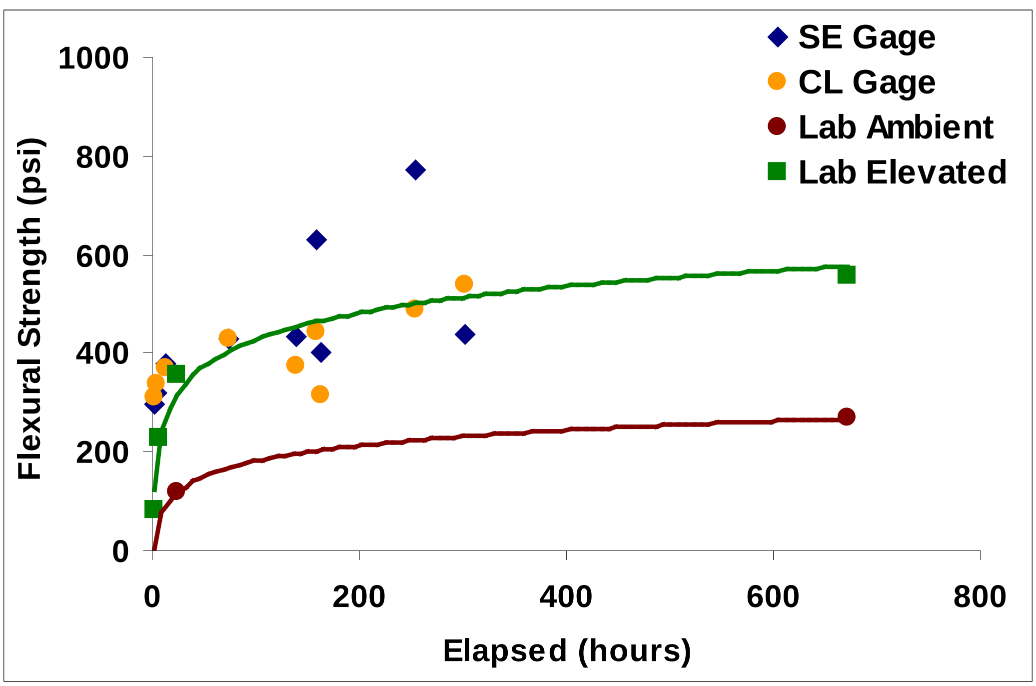


Figure 131. Crater 2, average calculated flexural strength during testing period compared to ambient and elevated laboratory testing conditions.

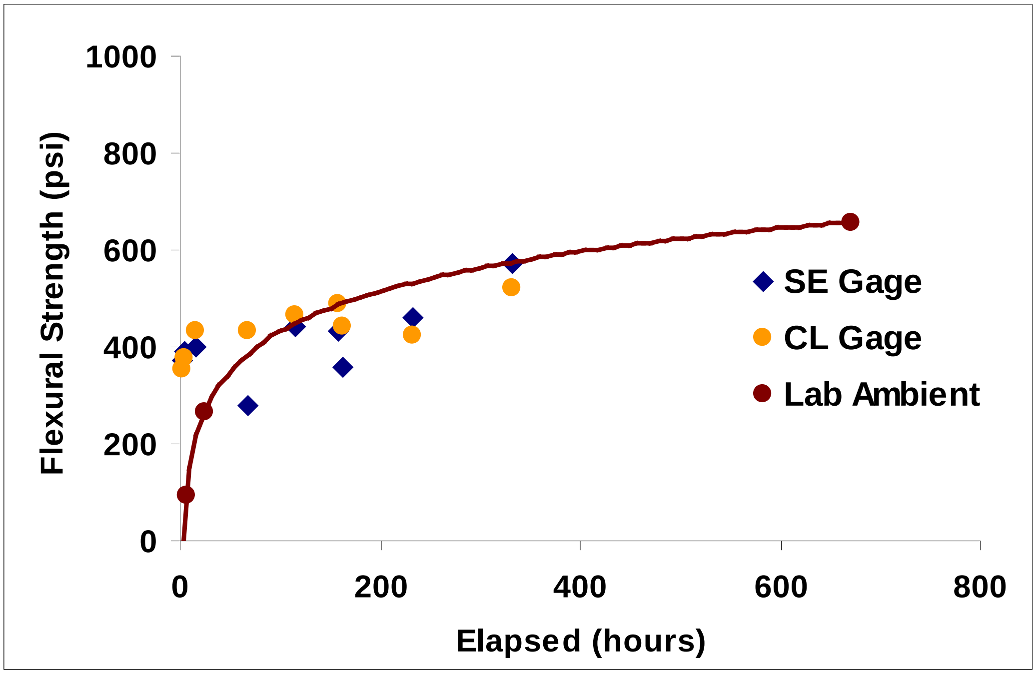


Figure 132. Crater 4, average calculated flexural strength during testing period compared to ambient laboratory testing condition.

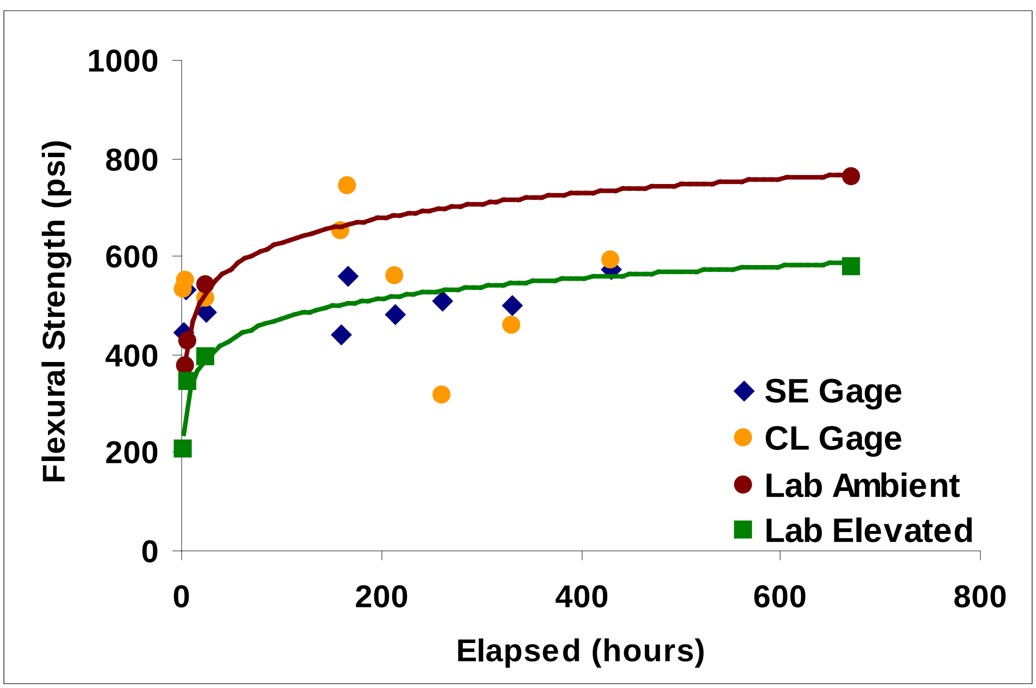


Figure 133. Crater 5, average calculated flexural strength during testing period compared to ambient and elevated laboratory testing conditions.

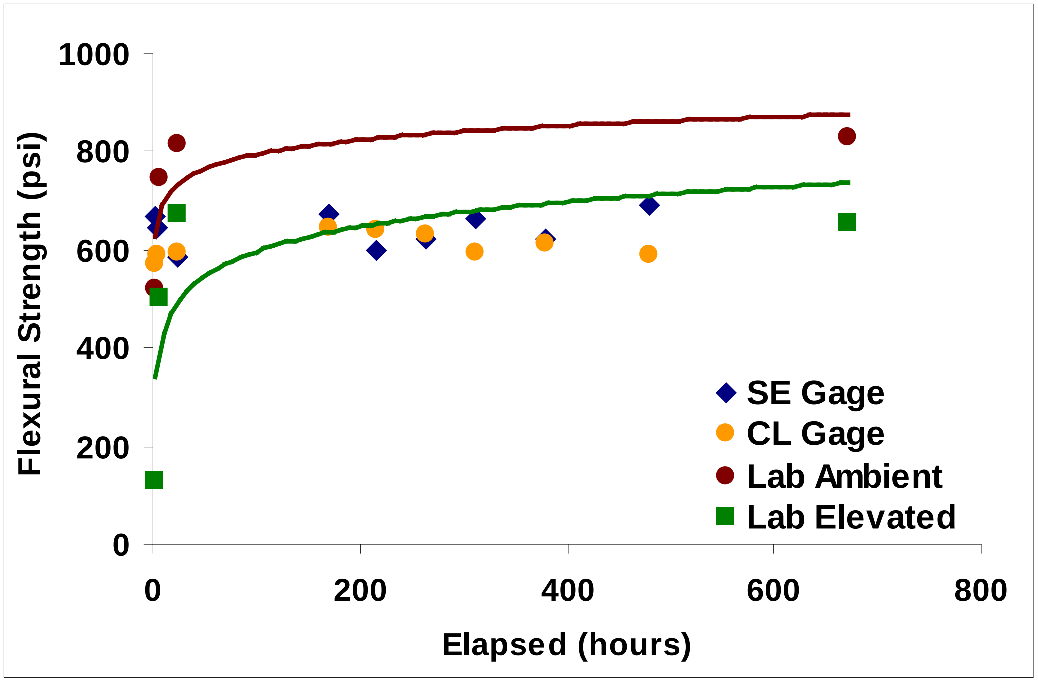


Figure 134. Crater 6, average calculated flexural strength during testing period compared to ambient and elevated laboratory testing conditions.

Initial 102 passes. At the conclusion of the initial 100 passes applied to each individual repaired crater, cracking that occurred was primarily of low severity.

- Crater 1, after trafficking for 102 passes (Figure 135), showed no change. Some of the shrinkage cracks extended, yet no structural distresses were observed. Due to the traffic, small pieces of hardened surface grout were breaking up, generating small pieces of FOD.
- On Crater 2 (Figure 136), the finished surface was rough and uneven. There was a low severity crack in the cold joint in the southeastern quadrant, generating small pieces of FOD.
- Prior to trafficking Crater 4, a longitudinal crack developed in Section 1 (northeastern quadrant). After 44 passes of the load cart, low severity intersecting cracks appeared in the northeastern quadrant and a low severity longitudinal crack formed in the southeastern quadrant (Figure 137). At the conclusion of 100 passes, a number of intersecting cracks had formed (Figure 138) and additional cracks formed in the northeastern quadrant, including an interesting concentric pattern.
- In Crater 5, after 104 passes of the load cart, a transverse crack in the northeastern quadrant and several transverse cracks, formed on the southern edge of the southeastern section, appeared (Figure 139).

- In Crater 6, there was movement in the joint between the two repaired slabs in the traffic lane after 100 passes of the load cart. Also, the surface powdered immediately after trafficking began, but did not appear to be damaging (Figure 140).

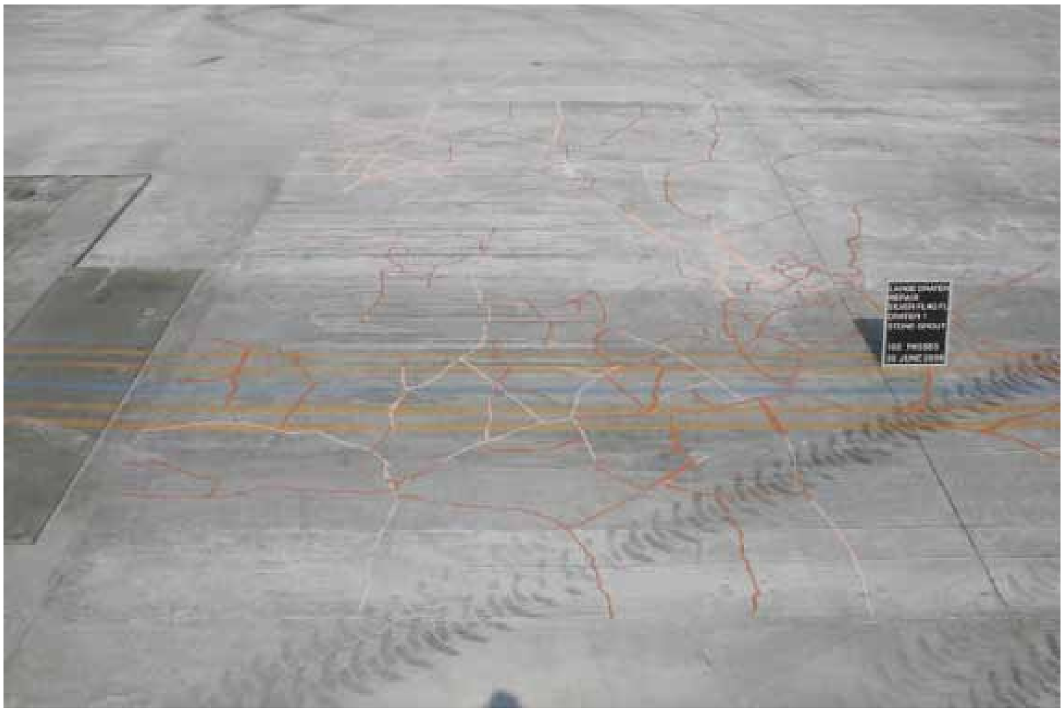


Figure 135. Crater 1, Stone & grout after 102 passes of load cart.

Figure 136. Crater 2, Pavemend EX-H after 102 passes of load cart.

Figure 137. Intersecting cracks after 44 passes in Crater 4.

Figure 138. Cracking after 100 passes in Crater 4.

Figure 139. Crater 5 after 100 passes of the load cart.

Figure 140. Crater 6 after 100 passes of load cart.

528 passes. After 528 passes of the load cart, in general, existing cracks were working open and more FOD was generated.

- In Crater 1, the cracking remained at a low severity level, existing cracks were extending, but not becoming wider, and more FOD was being generated as the surface was breaking up (Figure 141).
- In Crater 2, no structural distresses were observed, no FOD was being generated (Figure 142).
- Some additional low severity intersecting cracks formed in Crater 4 (Figure 143).
- In Crater 5, fine, low severity shrinkage cracks extended, as seen in the inset, but did not deteriorate (Figure 144).
- In Crater 6, the cold joint between the northeastern and southeastern quadrants had a width greater than 1 in and was generating FOD, as shown in the inset (Figure 145).

Figure 141. Crater 1 after 528 completed load cart passes.


Figure 142. Crater 2 after 528 completed load cart passes.

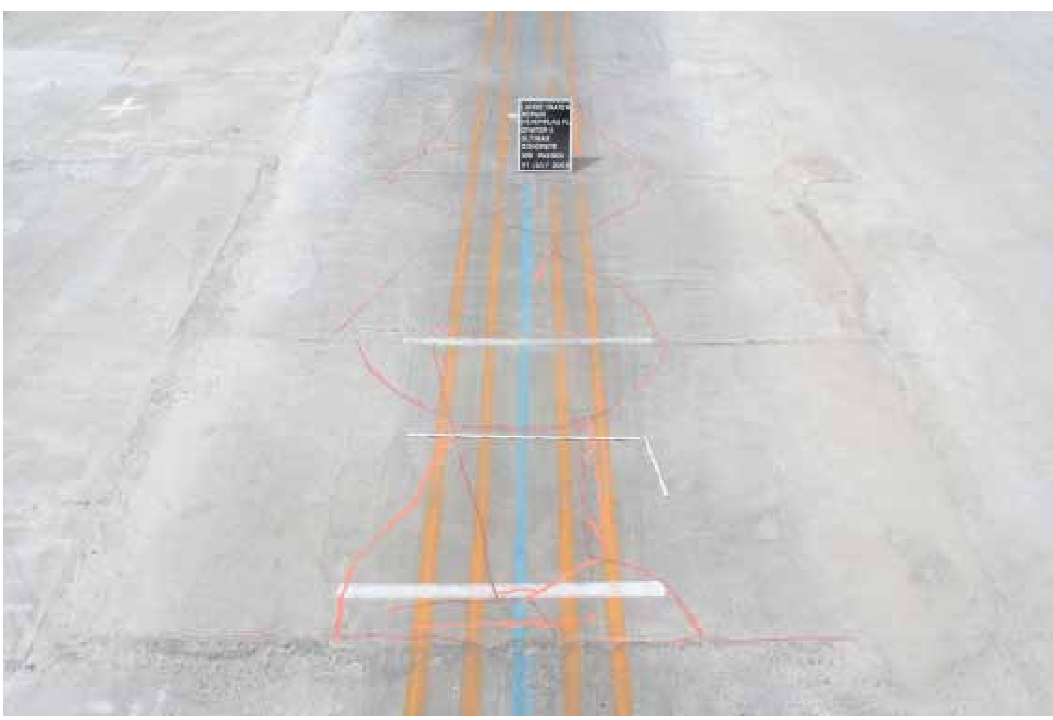


Figure 143. Crater 4 after 528 completed load cart passes.

Figure 144. Crater 5 after 528 completed load cart passes.

Figure 145. Crater 6 after 528 completed load cart passes.

1,008 passes. For all of the repaired craters, cracking continued, but none of the craters sustained sufficient damage to discontinue trafficking.

- In Crater 1, the cracks remained at a low severity level, with FOD still being generated (Figure 146 and Figure 147).
- In Crater 2, no significant structural distresses were observed (Figure 148).
- In Crater 4, the cracks were widening to a medium severity level, particularly along the edges of the stay-in-place forms, where ¼ in FOD was generated (Figure 149).
- In Crater 5, low severity longitudinal cracks formed in the southeastern quadrant (Figure 150).
- And in Crater 6, the joint between the repaired slabs had widened and the FOD was pushed about 2 ft out of the joint (Figure 151).

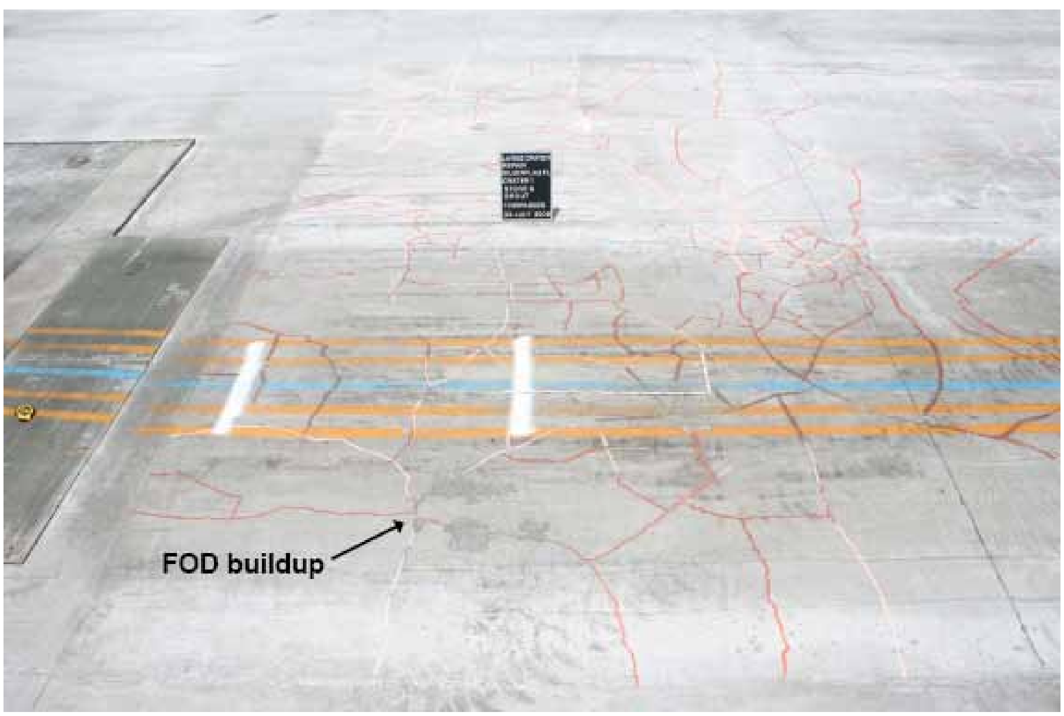


Figure 146. Crater 1 after 1,008 completed load cart passes.

Figure 147. Close-up of FOD, Crater 1 after 1,008 completed load cart passes.

Figure 148. Crater 2 after 1,008 completed load cart passes.

Figure 149. Crater 4 after 1,008 completed load cart passes.

Figure 150. Crater 5 after 1,008 completed load cart passes.

Figure 151. Crater 6 after 1,008 completed load cart passes.

2,016 passes.

- The surface condition of Crater 1 remained unchanged after 2,016 passes. More FOD was being generated, but the existing cracks had not widened (Figure 152).
- Low severity cracks appeared in Crater 2; however, they were not structurally significant, along the cold joints in the northeastern and southeastern quadrants (Figure 153).
- The cracking in Crater 4 brought the severity level to a medium shattered slab condition with the existing cracks widening and FOD sized ¼ to ½ in (Figure 154).
- In Crater 5, additional low severity longitudinal cracks developed (Figure 155), and cracks also appeared on the non-trafficked side.
- In Crater 6, the joint widened to 3-1/2 in and generated additional FOD (Figure 156).

Figure 152. Crater 1 after 2,016 completed load cart passes.

Figure 153. Crater 2 after 2,016 completed load cart passes.

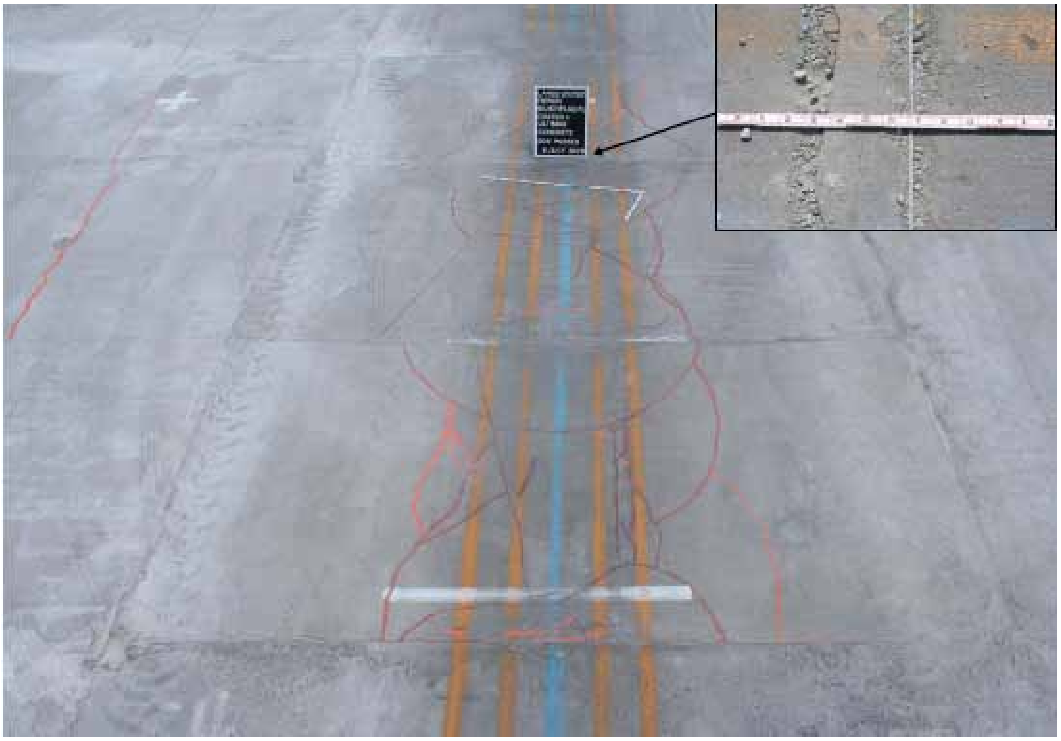


Figure 154. Crater 4 after 2,016 completed load cart passes.

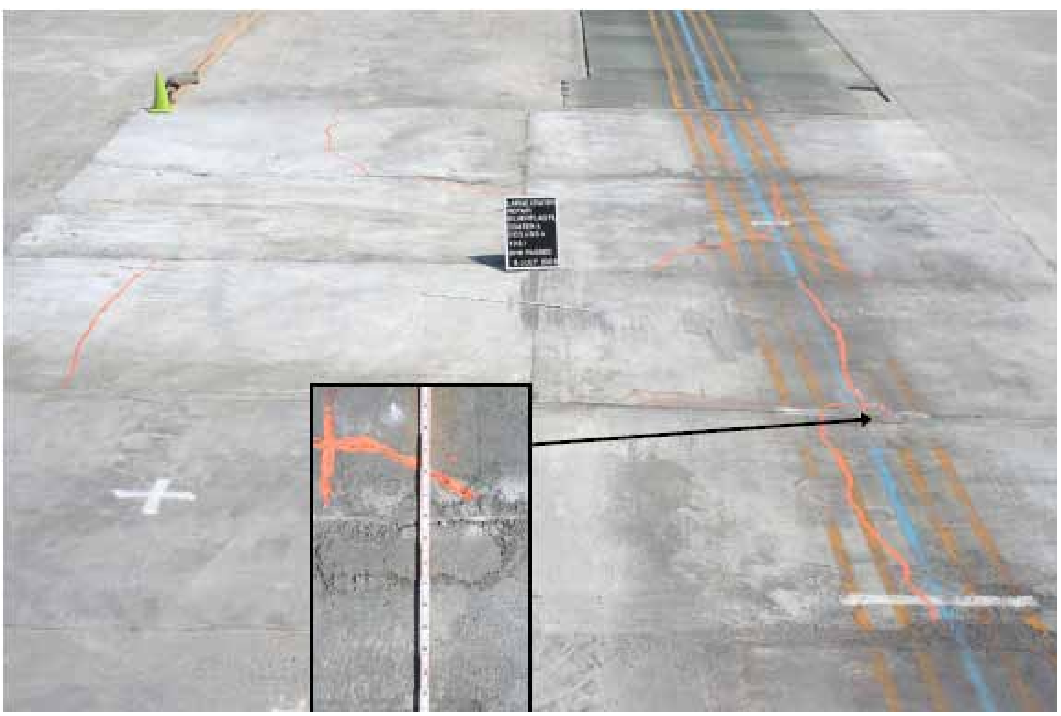


Figure 155. Crater 5 after 2,016 completed load cart passes.

Figure 156. Crater 6 after 2,016 completed load cart passes.

5,008 passes. All of the repaired craters sustained 5,008 passes of the F-15E load cart. The final surface condition for each repaired crater is shown in Figure 157 to Figure 164 . The final cracks in the repair were highlighted with orange paint.

- The numerous shrinkage cracks in Crater 1 remained low severity and did not widen (Figure 157 and Figure 158).
- In Crater 2, longitudinal cracks formed in the northeastern quadrant (Figure 159). The lateral cracks were the cold joints between the sect-ions. The rough finish on the Southeastern quadrant was more pron-ounced, but overall, little FOD was generated due to trafficking. Several cracks also formed in the traffic lane on the leading edge between the existing slab and the repair. As shown in the close-up (Figure 160), the FOD generated was largely from the uppermost surface.
- In Crater 4, all sections within the traffic lane contained longitudinal cracks and the condition of the slabs was considered to be fair (Figure 161).
- Crater 5 sustained primarily longitudinal cracks, particularly in the northeastern quadrant of the repair (Figure 162). There was also some spalling along the leading edge between the existing and repair slab in the traffic lane and also between the joint at the center of the traffic lane.

- The surface condition of Crater 6 sustained limited damage at the conclusion of 5,008 passes of the F-15E load cart (Figure 163). There was low severity spalling at the joint between the existing slab and the repair slab in the traffic lane. At the joint between the two repair slabs, spalling widened the joint generating some FOD material (Figure 164).

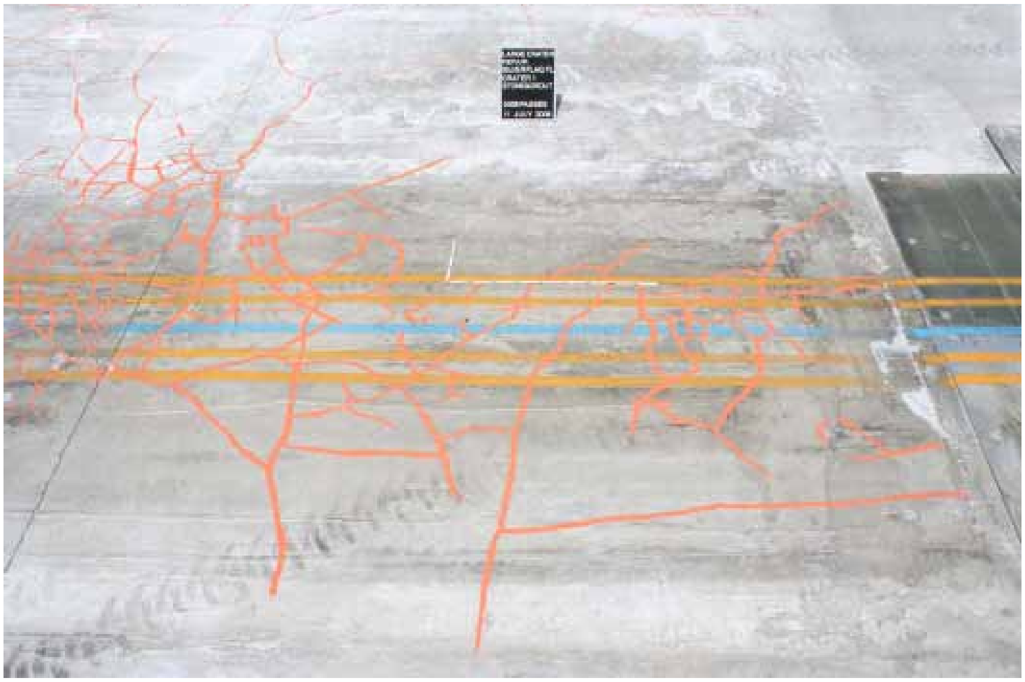


Figure 157. Crater 1 after 5,008 passes of load cart.

Figure 158. Highlighting cracks on the surface of Crater 1 after 5,008 passes of load cart.

Figure 159. Surface of Crater 2 after 5,008 passes of load cart.

Figure 160. Close up of surface of Crater 2 after 5,008 passes of load cart.

Figure 161. Surface of Crater 4 after 5,008 passes of load cart.

Figure 162. Surface of Crater 5 after 5,008 passes of load cart.

Figure 163. Surface of Crater 6 after 5,008 passes of load cart.

Figure 164. Close-up of joint spall between repaired slabs in traffic lane of Crater 6.

Pressure data readings.

Static pressure readings were collected by the pressure cells at both the edge and center locations when the F-15E load cart wheel was stopped directly above the gage location. The pressure readings are shown in Figure 165 to Figure 168 for Craters 2, 4, 5, and 6, respectively. The pressure readings for Crater 1 are not included since this is the control test section. In Crater 2, the pressure readings decreased with pass level (Figure 165), likely due to the longer period of time the CeraTech material required to gain strength, similar to the laboratory testing. The general trend for Crater 4 (Figure 166) indicates an increase in the pressure readings with increased pass level, due to the deterioration from cracking. Both Crater 5 (Figure 167) and Crater 6 (Figure 168) show steady pressure readings with increasing pass level as no structural cracks formed in these repairs.

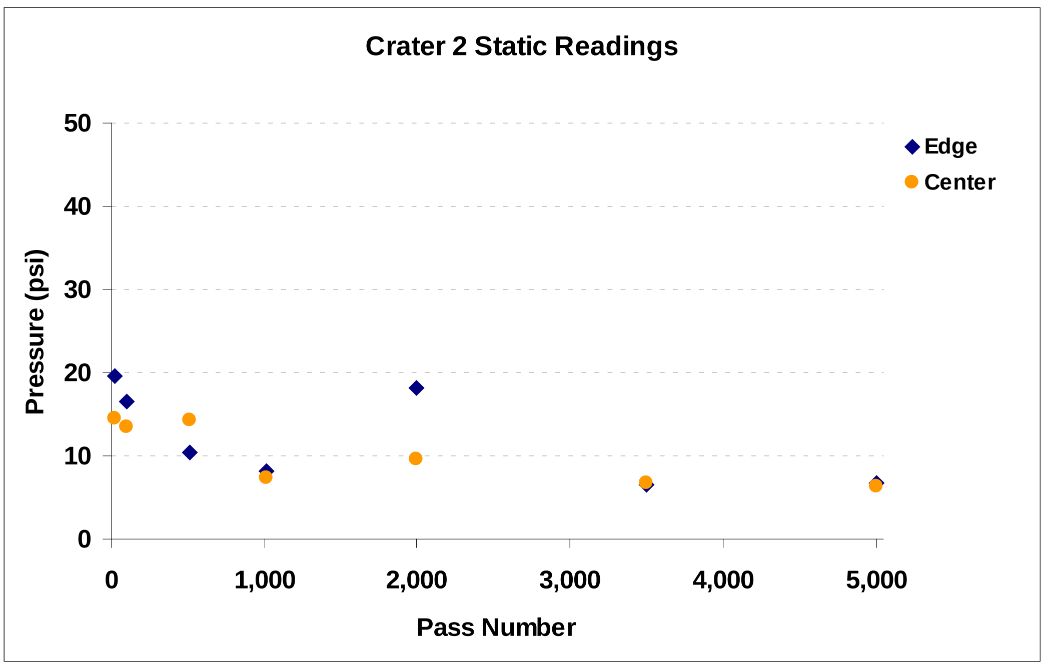


Figure 165. Crater 2, pressure cell readings during static load tests.

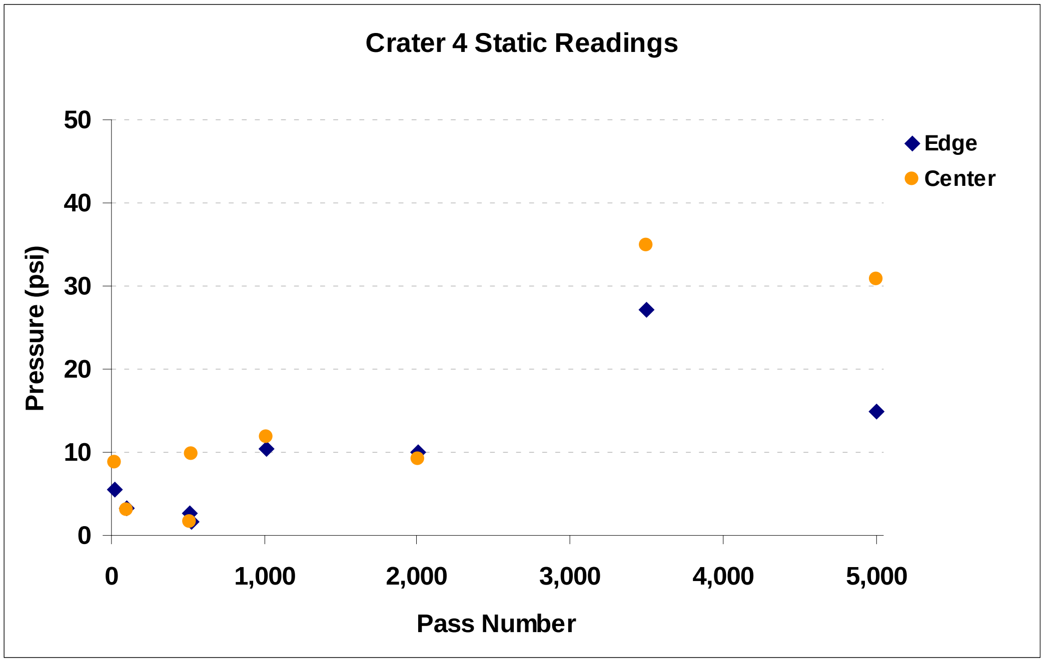


Figure 166. Crater 4, pressure cell readings during static load tests.

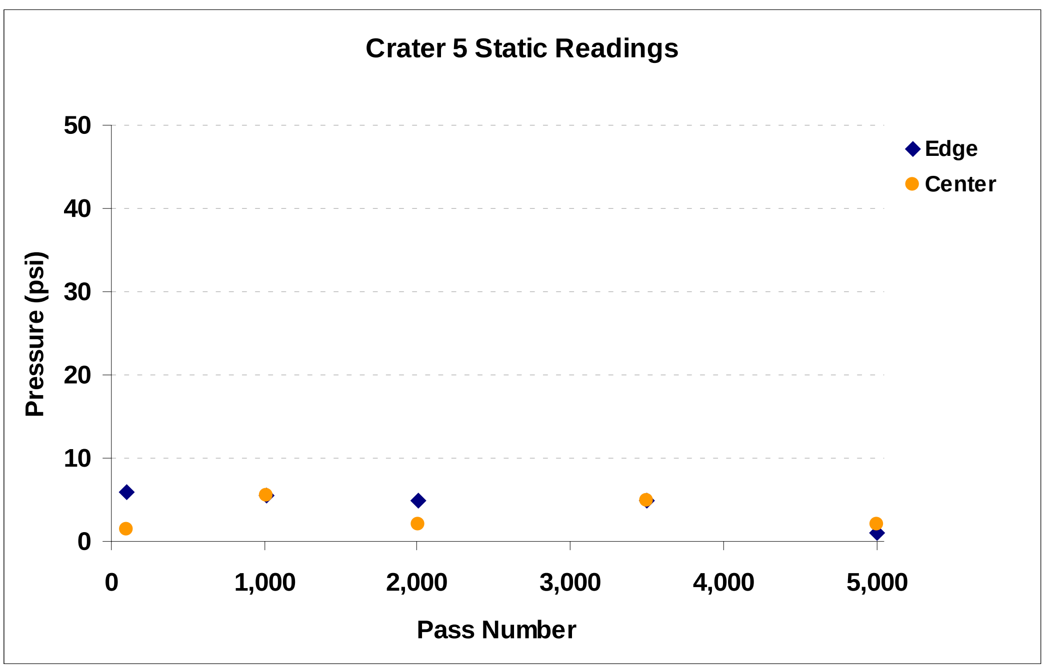


Figure 167. Crater 5, pressure cell readings during static load tests.

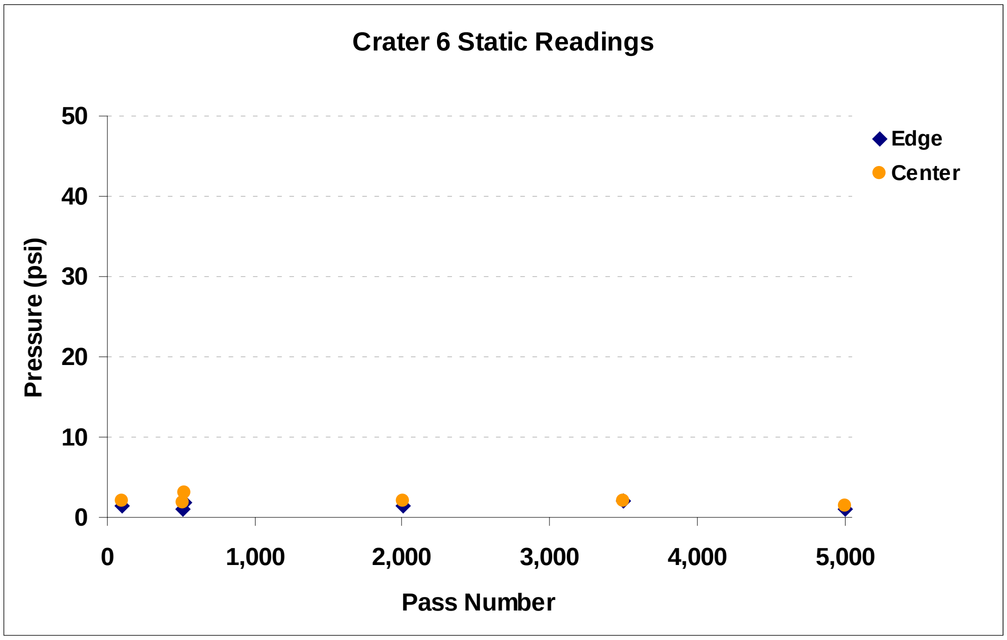


Figure 168. Crater 6, pressure cell readings during static load tests.

Post-Traffic Testing

Tensile strength.

At the conclusion of load cart trafficking, cores were collected by AFCESA for splitting tensile tests, conducted at their test facility. Six cores were collected in each test crater, with the exception of Crater 3. Three cores were collected from the sections within the traffic lane and three were collected from non-trafficked sections. The sketch in Figure 169 illustrates the locations where the core samples were collected. The photographs in Figure 170 through Figure 175 show representative cores collected for testing.

The three core specimens collected in the traffic lane from Crater 2 (CeraTech, Pavemend EX-H) were deemed un-testable as they were fractured when removed from the core hole (Figure 171). Instead, tensile testing was conducted on the cores collected from the non-trafficked side (Figure 172). Note the voids indicating the layering from the placement of multiple batches. Figure 173 shows Core 2 located within the traffic lane in Crater 4 (Ultimax Concrete). Figure 174 shows a core collected from the wheel path of Crater 5 (Degussa, Thoroc 10-61). Toward the surface of the core – left side of the photograph – there are voids, indicating where one mix was placed over a previous layer due to multiple batching. This was

typical of material placed in thin layers with the 2 yd^3 portable mixer. Figure 175 is Core 2 in the traffic lane, above the pressure cell in Crater 6.

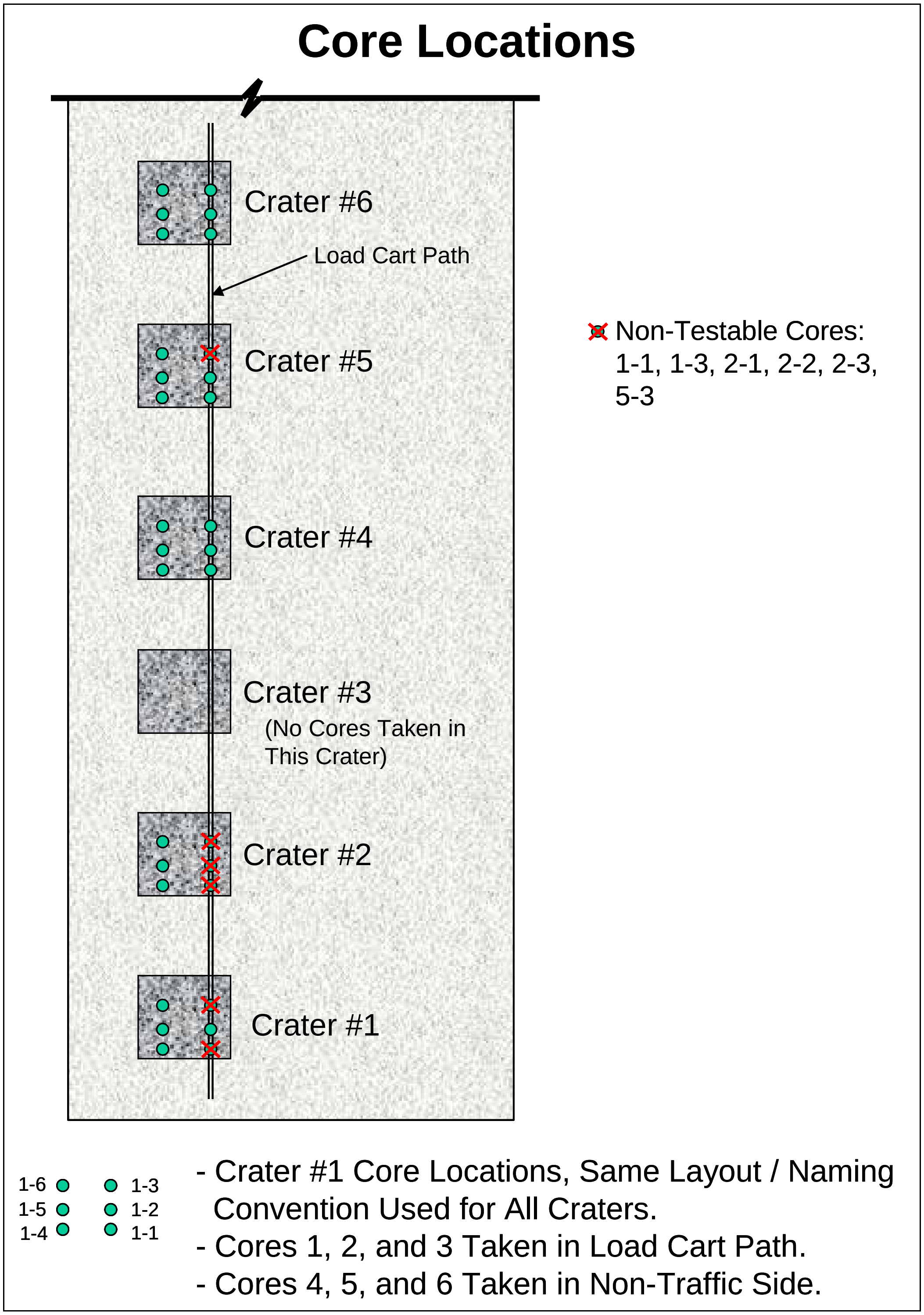


Figure 169. Core hole locations in each test crater showing cores not acceptable for testing (from AFCESA).

Figure 170. Core 2 from Crater 1 above pressure cell in traffic lane, stone and grout (control).

Figure 171. Core 1 from Crater 2 above pressure cell in traffic lane CeraTech Pavemend EX-H.

Figure 172. Core 5 from Crater 2 on non-trafficked side of repair, CeraTech Pavemend EX-H showing irregular layers of material separated by void spaces.

Figure 173. Core 2 from Crater 4 within traffic lane, Ultimax Concrete.

Figure 174. Core 2 from Crater 5, Degussa Thoroc 10-61 material.

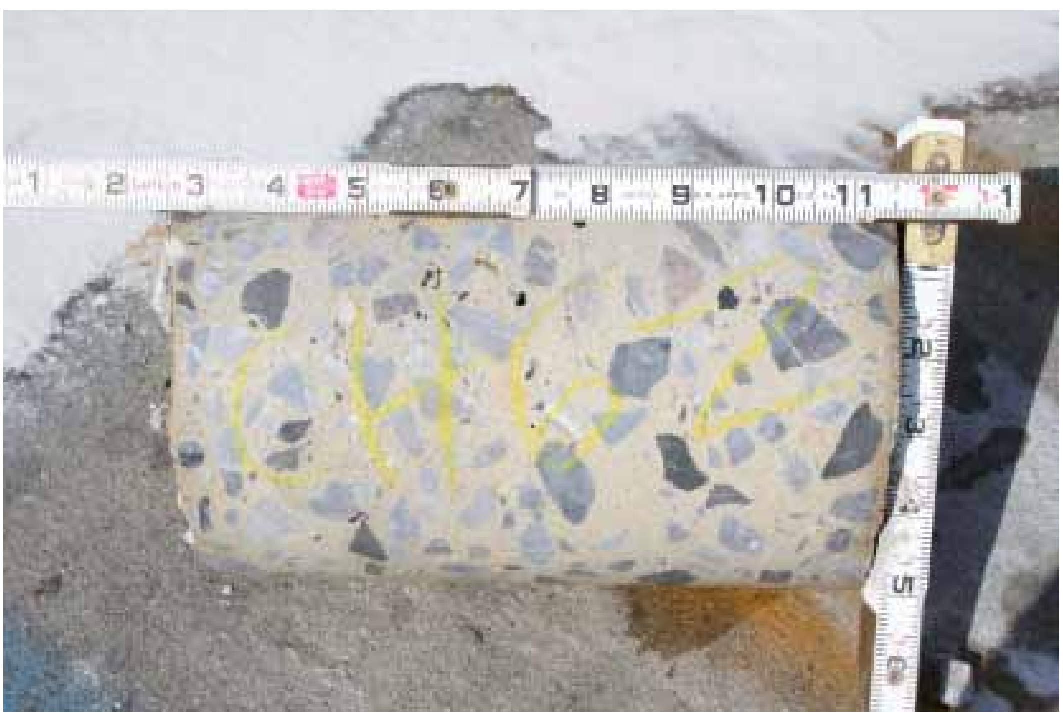


Figure 175. Core 2 from Crater 6 above pressure cell, CTS Rapid Set DOT Cement.

The chart in Figure 176 and Table 21 summarize the tensile testing results. Cores from the CTS Cement, Rapid Set DOT cement (Crater 6) had the highest tensile strengths. This was a very consistent mix, and it was mixed using a volumetric mixer. The Ultimax Concrete material, Crater 4, varied in strength from 454 to 721 psi, likely due to the variation in the quantity of mix water added to the batches. Comparatively, the RS materials from Degussa (Crater 5) showed decent strengths, while the tensile strengths for the CeraTech were lower (Crater 2). Overall, the RS materials showed higher strengths than the stone and grout material (Crater 1).

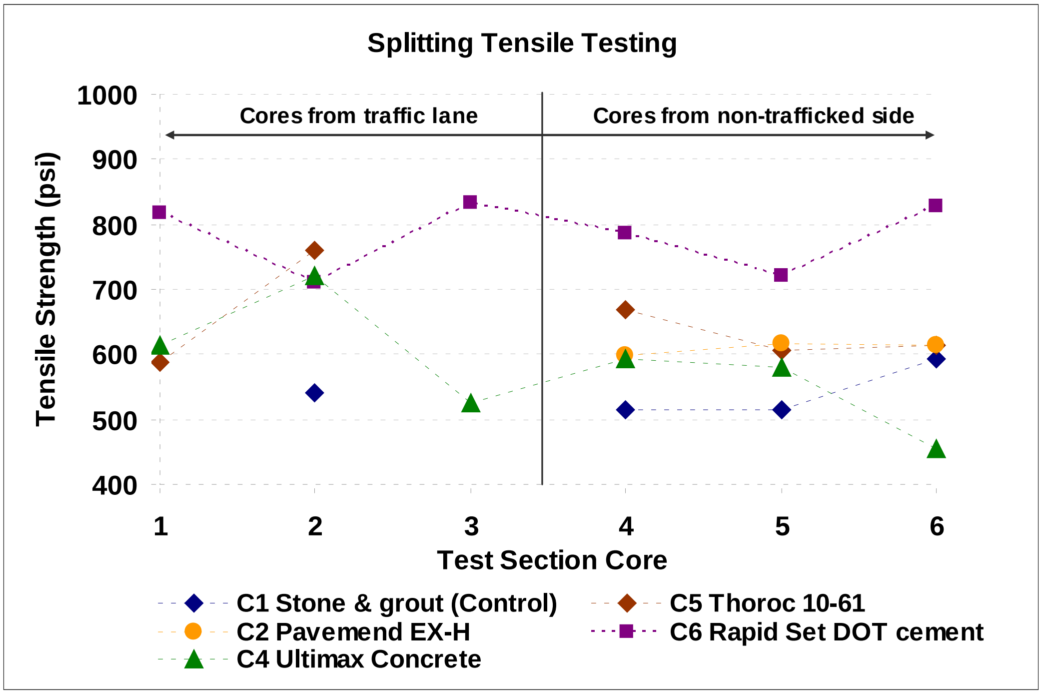


Figure 176. Results of splitting tensile tests on cores drilled out of test craters.

Table 21. Splitting tensile test results of core samples drilled in test craters.

Core Number	Flexural Strength (psi)				
	Crater 1	Crater 2	Crater 4	Crater 5	Crater 6
1	Not tested	Not tested	613	587	818
2	541	Not tested	721	761	711
3	Not tested	Not tested	525	Not tested	834
4	514	597	594	669	785
5	516	617	580	607	721
6	594	614	454	613	828

Discussion of dynamic load tests

Rod and level surveys.

Although an 8 in cap was the target depth for each crater, the level survey data shows some variation. Crater 4 had the thinnest RS cap at a nominal 7.6 in. Craters 1 and 5 were nominally 8.5 in, Crater 2 was a nominal RS cap of 6.8 in over the 2 in of aggregate, while Crater 6, at a nominal 9 in, was the thickest cap. The surface survey readings collected during traffic-cking show insignificant elevation change with the number of passes. None of the craters exhibited settlement or uplift that exceeded the ¾ in criteria for elevation differential with the existing pavement. This performance of the material was anticipated given that it is cementitious. All of the crater repairs successfully met this criteria.

HWD data.

In general, the comparison of deflection readings between the trafficked and non-trafficked sides reflect the effects of trafficking. Overall, the normalized deflection readings at the center of the plate increased as the number of completed passes increased. There are a few instances where the deflection readings are higher and then appear to recover, or become lower, during a later test. Examples are the Crater 1 non-trafficked location, and the Crater 4 center and non-trafficked locations. This is possibly due to the positioning of the plate in a crack-free area to obtain reasonable readings. This also occurred during the 2-hr early-age test for materials in Craters 2, 4, and 6, again mostly on the non-trafficked side, indicating that the material may not have fully cured when the testing was conducted. Typically, the traffic lane was first to be repaired to provide as much curing time as possible.

The normalized deflection data for Craters 4 and 5 reflected the presence of cracks in the structural cap with large deflection readings at the center of the plate (the 0 in sensor). Normalized deflection readings at the center of the plate for Crater 4 exceeded 80 mils, at both the edge and center locations, beginning at the 7-day test. However, while cracking developed in Crater 5, the normalized deflection readings at 0 in neared and slightly exceeded 60 mils at the edge and center locations, respectively, but did not further increase. The deflection basins from Crater 6 showed relatively low deflection readings throughout the testing period at all locations.

For Crater 1, the center deflection readings increased with increased passes, and exceeded 80 mils after 1,008 passes. For the most part in Crater 2, the deflection readings increased with increased passes, yet there is a significant increase from 2,016 to 5,008 passes as the readings jumped more than 20 mils. Since both repairs (Craters 1 and 2) had fine cracks present, it is possible that the dynamic loading may have been continuously working the cracks and increasing the tensile stress at the bottom of the slab. The shrinkage cracks in Crater 1 did not continue to widen during trafficking; and in Crater 2, the cracks were miniscule. Another possibility may be the effect of the irregular cold joints that formed between the small batches of material during the repair work. This may be an issue worthy of further investigation.

PSPA Young's modulus.

Modulus values for Crater 1 fluctuated from a high of 4.8 x 10^6 psi then decreased to 3.2 x 10^6 psi, then increased again and exceeded the ETL recommended value after 239 hours. No laboratory testing was conducted on this material. For Crater 2, the readings for the material at an early age ranged from 2.5 to 3.1 x 10^6 psi. After 72 hours, the values were lower than the recommended ETL values, but reached the value after 300 hours. For Crater 4, the modulus value reached the ETL recommended value (centerline, CL, gage) after 158 hours. After 330 hours, the modulus values exceeded the ETL value and trended with the ambient lab values. In Crater 5, the modulus values reached a maximum value of 6.2 x 10^6 psi after 166 hours. For Crater 6, the modulus values remained consistent during the testing period and exceeded the ETL recommended value even from early age.

PSPA calculated flexural strength.

Values for Crater 1 were calculated although no laboratory testing was conducted on this material. The flexural strength scatters 400 psi during the initial 72 hours, and then increases significantly. For Craters 2, 4, and 5, the calculated flexural strength trends with the laboratory data with values ranging from 400 to 450 psi. Calculated flexural strengths for Crater 6 also fall between the ambient and elevated laboratory temperature conditions and remain consistent, around 600 psi, throughout the testing period.

Pavement condition surveys.

The focus was on structural distresses and FOD when conducting the condition surveys during the trafficking. While the surface of the repairs for Craters 1, 2, 4, and 5 had a rough texture, none of them exceeded the elevation difference criteria. Crater 4 concluded in fair condition due to the extensive cracking that formed within the traffic lane creating a shattered slab condition. Even with the density of cracks, 2,016 passes were completed on the repair with the cracks not widening extensively. For Craters 1, 2 and 5, all were considered in good to very good condition after 5,008 passes. The same occurred with Crater 6, which was also considered to be in very good condition after trafficking. All of these repairs would likely continue in operation with regular maintenance required.

Static pressure readings.

The static pressure measurements from the pressure cells at the edge and center locations show the distribution of the aircraft load with increasing pass number. Craters 5 and 6 showed the lowest pressure readings, less than 10 psi, indicating that the material distributed the load. In Crater 4, the pressure readings increased as the amount and severity of the cracks increased. Interestingly, in Crater 2, the pressure readings under static loading started high and then decreased, perhaps due to the slow strength gain of the material.

Tensile strength of field cores.

The tensile strength test results of the core samples show the effect of the multiple batches of the repairs. The results for Crater 6 were the highest with a very consistent mixture. The effect of layering for other RS materials is shown with the lower strengths. However, the RS materials did show higher strengths than the stone and grout repair.

7 Conclusions

The purpose of this study was to test commercially available RS cementitious materials for use in the expedient repair of large craters in bomb-damaged airfield runways. The selected RS materials were evaluated in under controlled laboratory conditions following a spall materials testing protocol. The selected RS materials were used to repair a simulated large crater that, once completed, was subjected to trafficking with a load cart equipped with an F-15E tire. Based on the laboratory and full-scale field conditions, the following conclusions are made:

1. The laboratory testing provided familiarity with the behavior of the selected RS materials prior to using it under full-scale conditions.
2. Testing the RS material at an elevated temperature condition clearly showed the difference in behavior of the material. The materials protocol reflects the need to test under anticipated temperature conditions. Elevated temperatures of the air, RS materials, aggregates, and water significantly impact the mixing and working time with RS mixes.
3. While not always feasible, the 2 hr early-age test was valuable in establishing potentially successful RS materials and is considered a critical early age.
4. The laboratory tests selected were considered germane to the characteristics of large craters and were composed heavily of strength properties. It is important that a comprehensive laboratory evaluation should be completed to reasonably compare the properties of the RS materials.
5. The laboratory set time test proved to be important.
6. Based on the laboratory test results, the RS materials that consistently showed the best performance, as evaluated by the materials testing protocol, were CTS Cement Rapid Set DOT cement and Degussa Thoroc 10-61 Repair Mortar.
7. The use of RS materials alone will not achieve rapid repairs of large craters. The mixing equipment was a significant limiting factor in this study.
8. Operating under the experimental scenario of using RS materials with a 2 yd^3 portable mixer, none of the repairs for a 23 or 34 yd^3 volume were completed within the objective time frame of 4 hr. This scenario showed that it is possible to repair a large crater using RS materials and an undersized mixer, yet it is quite labor intensive. However, a minimum of 8 hr

was needed to repair the structural cap layer under the conditions used in the full-scale field trial. An average of 10 hr and a crew of 12 to 16 were required to complete one crater repair. Following an attack, additional time would be needed for damage assessment and to prepare the crater. Given the time duration and intensity of completing large crater repairs, a larger team size is recommended to reduce fatigue.

9. To attain adequate mixing with the portable 2 yd^3 mixer, or any piece of mixing equipment, do not overload, and distribute the materials evenly to prevent clogging and facilitate uniform mixing.
10. Maintain the mixing equipment by periodically cleaning it out to prevent a build-up of hardened material.
11. Related to the item above, always be mindful of the quantity of water available in the water truck – running out of water when using RS materials was disastrous. Always have immediately available something that will kill the mix so that it does not set up in the mixer.
12. The 2 yd^3 portable mixer requires modifications to strengthen it for expedient large crater repair. Examples include using a longer chute to discharge mixed material, and changing the spacing on the grate cover due to clogging, etc. The use of the volumetric mixer to complete the repair in Crater 6 provided a well mixed uniform material. Whereas the volumetric mixer used in the field trial was unsuitable for air transport, it demonstrated that a larger piece of mixing equipment (4 - 6 yd^3) would likely be sufficient for a large crater application.
13. Mixing and placing RS materials in a quadrant (1/4 of the crater) using a 2 yd^3 mixer was too large a volume to place. With quadrants 15 ft x 15 ft, divide the quadrant in half by securing a temporary form board perpendicular to the direction of traffic. Completing a crater repair with it divided into 8 sections was more manageable, and allowed the section to be completed in the fewest number of lifts.
14. The number of products and additional steps to complete an expedient crater repair must be minimized. These extra items required additional time and equipment. Examples include the use of evaporation reducer and curing compound for the Crater 5 repair, and the use of stay-in-place forms in Craters 3 and 4.
15. Temperature histories revealed that when craters are repaired in multiple sections (such as 8), temperatures in the crater corners reached higher maximum temperatures than in the center of mass. This is the reverse of what typically occurs in a monolithic pour.
16. Regarding the use of the laboratory test protocol to eliminate RS materials from consideration in the field - the performance of both RS materials that

performed well in the laboratory also performed well under full-scale field conditions (CTS Cement Rapid Set DOT Cement (Crater 6), and Degussa Thoroc 10-61 Rapid Repair Mortar (Crater 5).

17. Under field conditions, two RS materials, CTS Cement Rapid Set DOT Cement (Crater 6) and Degussa Thoroc 10-61 Rapid Repair Mortar (Crater 5), sustained the minimum operating requirement of 100 passes of the F-15E load cart. Both materials also sustained 5,008 passes of the F-15E load cart with low severity cracking. While the CeraTech Pavemend EX-H (Crater 2) material did not perform well under laboratory conditions, during the field trial this RS material withstood 5,008 passesl, displaying only low severity cracking.
18. The use of RS materials alone will not achieve rapid repairs of large craters. The mixing equipment was a significant limiting factor in this study.

It is recommended that additional information on RS materials should be added to the database of materials. The laboratory testing might consider recommendations based on the material type.

References

American Concrete Institute (ACI). 2006. *Guide for the Selection of Materials for the Repair of Concrete.* ACI 546.3R-06. Farmington Hills, MI: American Concrete Institute.

American Society for Testing and Materials (ASTM). Reapproved 2005. Standard test method for compressive strength of cylindrical concrete specimens. In *Annual Book of ASTM Standards.* C 39.West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2002. Standard test method for flexural strength of concrete (using simple beam with third-point loading). In *Annual Book of ASTM Standards.* C 78. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2004. Standard test methods for time of setting of hydraulic cement by Vicat Needle. In *Annual Book of ASTM Standards.* C 191. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2005. Standard test method for time of setting of concrete mixtures by penetration resistance. In *Annual Book of ASTM Standards.* C 403. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2002. Standard test method for static modulus of elasticity and poisson's ratio of concrete in compression. In *Annual Book of ASTM Standards.* C 469. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2002. Standard test method for splitting tensile strength of cylindrical concrete specimens. In *Annual Book of ASTM Standards.* C 496. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2005. Standard test method for linear shrinkage and coefficient of thermal expansion of chemical-resistant mortars, grouts, monolithic surfacings, and polymer concretes. In *Annual Book of ASTM Standards.* C 531. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2003. Standard test method for resistance of concrete to rapid freezing and thawing. In *Annual Book of ASTM Standards.* C 666. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2005. Standard test method for bond strength of epoxy-resin systems used with concrete by slant shear. In *Annual Book of ASTM Standards.* C 882. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2004. Standard test method for determining age at cracking and induced tensile stress characteristics of mortar and concrete under restrained shrinkage. In *Annual Book of ASTM Standards*. C 1581. West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2004. Standard test methods for density of soil and soil-aggregate in place by nuclear methods (shallow depth), In *Annual Book of ASTM Standards*. C 2922 West Conshohocken, PA: American Society for Testing Materials.

American Society for Testing and Materials (ASTM). Reapproved 2004. Standard test method for water content of soil and rock in place by nuclear methods (shallow depth). In *Annual Book of ASTM Standards*. D 3017. West Conshohocken, PA: American Society for Testing Materials.

BASF Building Systems. 2006. Product Data Sheet, 10-61 Rapid Mortar, Shakopee, MN: BASF Building Systems,. Available at: http://www.BASFFuildingSystems.com.

Beyer, G. T., and T. E. Bretz. 1981. *Flush Bomb Damage Repair Field Testing*, Final Report ESL-TR-81-48. Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

Boyer, J. P., C. Kistler, U. Nandi, J. Pfau, S. Rohleder, M. J. Snyder, and A. S. Kubo. 1982. *Advanced Materials Development for Repair of Bomb Damaged Runways*. Final Report ESL-TR-82-14. Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

Campbell Scientific. Inc. 2004. CS616 and CS625 water content reflectometers instruction manual. http://www.campbellsci.com.

CeraTech, Incorporated (no date) Product Information Sheet, CeraTech Incorporated, Alexandria, VA: http://www.ceratechinc.com/index.asp.

CTS Cement (no date) Product Specification for: Rapid Set® D.O.T. Cement, Cypress, CA: CTS Cement Manufacturing Corporation. www.ctscement.com.

CTS Cement (no date) Rapid Set® D.O.T. Cement – Datasheet. Cypress, CA: CTS Cement Manufacturing Corporation. http://www.ctscement.com/index.html.

Fowler, D. W., D. R. Paul, B. F. McCullough, and A. H. Meyer. 1982. *Methyl Methacrylate Polymer-Concrete for Bomb Damage Repair*. Final Report ESL-TR-82-04. Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

Geokon, Inc. 2002. Model 3500 earth pressure cells instruction manual. http://www.geokon.com.

Hammitt, G. M., J. W.P. Patin, and R. Devens 1986. *Technical Evaluation Reports of Airfield Damage Repair Solution*. Final Technical Report GL-86-17. Vicksburg, MS: Geotechnical Laboratory, Department of the Army, Waterways Experiment Station, Corps of Engineers.

Hoff, G. C. 1975. *A Concept for Rapid Repair of Bomb-Damaged Runways Using Regulated-Set Cement*. Final Technical Report C-75-2. Vicksburg, MS: Concrete Laboratory, U.S. Army Engineer Waterways Experiment Station.

Hokanson, L. D. 1975. *Tyndall AFB Bomb Damage Repair Field Test, Documentation and Analysis*, AFWL-TR-74-226, Kirtland Air Force Base, NM: Air Force Weapons Laboratory, Air Force Systems Command.

Hokanson, L. D. Capt, USAF ,and R. S. Rollings, Jr. 1LT USAF 1975. *Field Test of Standard Bomb Damage Repair Techniques for Pavements*, AFWL-TR-75-148, Kirtland Air Force Base, NM: Air Force Weapons Laboratory, Air Force Systems Command.

Klieger, P., and J. F. Lamond 1994. *Significance of Tests and Properties of Concrete and Concrete-Making Materials*. STP 169C. Philadelphia, PA: American Society for Testing and Materials (ASTM).

Kubo, A. S., R. K. Moates, E. A. Godfrey, M. D. Hoffman, R. Teegarden, R. B. Bennett, C. Kistler, R. Berry, and D. Ounanian 1986. *Advanced Bomb Damage Repair System Phase II: Prototype Design*, Final Technical Report, ESL-TR-84-38, Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

McNerney, M. T. 1980. *Field Test of Expedient Pavement Repairs.* Final Report ESL-TR-80-51, Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

Mindess, S., and J. F. Young 1981. Concrete, Prentice-Hall, Inc. New Jersey.

Mr. Patrick Watson. 2006. Communication.

Stroup, T., D. Reed, and G. M. Hammitt II 1986. *Airfield Damage Repair Techniques of 18th Engineer Brigade in Europe*, Miscellaneous Paper GL-86-1, Vicksburg, MS: Department of the Army, Waterways Experiment Station, Corps of Engineers.

Sugama, T., L. E. Kukacka, D. W. Huszagh, S. Shteyngart, and N. R. Carciello 1984. *Advanced Water-Compatible Materials for Bomb Damage Repair*. Final Report ESL-TR-84-03. Tyndall Air Force Base, FL: Engineering & Services Laboratory, Air Force Engineering and Services Center.

U.S. Air Force 2002. *Airfield pavement evaluation, standards and procedures.* Engineering Technical Letter 02-19. Tyndall AFB: Air Force Civil Engineer Support Agency.

U.S. Air Force 2008a. Airfield Damage Operations, Air Force Pamphlet 10-210, Volume 4, HQ AFCESA/CEXX, www.e-publishing.af.mil

U.S. Air Force 2008b. Testing Protocol for Rigid Spall Repair Materials, ETL 08-2, AFCESA/CEOA, Tyndall AFB, FL.

U.S. Army Corps of Engineers. 1995. *Standard Test Method for Determining the Modulus of Soil Reaction*. CRD-C 655-95 Vicksburg, MS: Waterways Experiment Station.\ Troxler Electronic Laboratories, Inc. 2003. Model 3440 surface moisture-density gauge, manual of operation and instruction. www.troxlerlabs.com.

U.S. Army Corps of Engineers 2002. *O&M: Airfield Damage Repair*. Unified Facilities Criteria 3-270-07, Washington D.C.: Headquarters, U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers 2001. *Concrete Surfaced Airfields Pavement Condition Index (PCI)*. Unified Facilities Criteria 3-270-05, Washington D.C.: Headquarters, U.S. Army Corps of Engineers.

Vaysburd, A. M., P. H. Emmons, J. E. McDonald. 1999. *Performance Criteria for Concrete Repair Materials, Phase II*. Summary Report, Technical Report REMR-CS-62, Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station.

Appendix A – Laboratory Test Data

	LARGE Crater Repair Project					Date	3-May-06	
					Batch size:	6.00	cu. Ft.	
Material Name:		RapidSet - DOT Cement				Ambient		
		CMB checkin number		# 060132				
Time Cast:	0840 Hours			Total Mixing Time:		6 Minutes		
Lab Ambient Temp.:		71 F	Water Temp.:		72 F	Material Temp.:		73 F
6x12 cyl for compressive & modulus					Initial Set:	60 minutes		
Specimen Labels	Specimen Number	Test Time			Final Set:	80 minutes		
123 LC-1B	78	2 Hours	Strength		Rock-and-Tilt Revolving-Drum Mixer			
123 LC-1B	79	2 Hours	Strength					
123 LC-1B	80	2 Hours	Strength					
123 LC-1B	81	6 Hours	Strength		Water	50 lbs	(58.3 total)	
123 LC-1B	82	6 Hours	Strength		Retarder	3 little bags		
123 LC-1B	83	6 Hours	Strength		DOT Cement	3 sacks	(150 pounds)	
123 LC-1B	84	24 Hours	Strength		MMC Conc. Sand	300 lbs	CMB Lab Stock	
123 LC-1B	85	24 Hours	Strength		# 57 Limestone	450 lbs	CMB Lab Stock	
123 LC-1B	86	24 Hours	Strength					
123 LC-1B	87	28 Days	Strength		Goal: 5 +- 1" slump			
123 LC-1B	88	28 Days	Strength					
123 LC-1B	89	28 Days	Strength		Added 1 gallon water to increase slump			
123 LC-1B	90	2 Hours	Modulus		Total water - 58.3 pounds			
123 LC-1B	91	2 Hours	Modulus		Slump: 4-inches			
123 LC-1B	92	2 Hours	Modulus					
123 LC-1B	93	6 Hours	Modulus					
123 LC-1B	94	6 Hours	Modulus					
123 LC-1B	95	6 Hours	Modulus					
123 LC-1B	96	24 Hours	Modulus					
123 LC-1B	97	24 Hours	Modulus					
123 LC-1B	98	24 Hours	Modulus					
123 LC-1B	99	28 Days	Modulus					
123 LC-1B	100	28 Days	Modulus					
123 LC-1B	101	28 Days	Modulus					
We need 4.8 cubic feet to cast 24 6x12 cylinders								
Each sack yields 2.0 cu. Ft. with added aggregates								
So, for 4.8 cu ft we need 3 sacks DOT Cement for 6 cubic feet (to keep it sack quantities)								
Each sack of DOT Cement weighs 50-lbs. and requires:								
2.0 gallons water, 100 lbs concrete sand, and 150 pounds #57 stone per RapidSet.								
1, 25-gram bag of RapidSet retarder per sack of DOT Cement to retard the mixture 20 minutes.								
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket, retarder in 2/3 bucket.								
Sand and stone in mixer first. Add 2/3 bucket water with retarder. Add DOT Cement.								
Mix 2 to 3 minutes. Add additional water to bring to goal of						Goal: 5 +- 1" slump		

	LARGE Crater Repair Project					Date	3-May-06	
					Batch size:	6.00	cu. Ft.	
Material Name:		RapidSet - DOT Cement				Ambient		
		CMB checkin number		# 060132				
Time Cast:	0953 Hours			Total Mixing Time:		6 Minutes		
Lab Ambient Temp.:		72 F	Water Temp.:		72 F	Material Temp.:		73 F
Specimen	Specimen	Test						
Labels	Number	Time				Initial Set:	62 minutes	
123 LC-1B	102	2 Hours		Flex Beam		Final Set:	73 minutes	
123 LC-1B	103	2 Hours		Flex Beam				
123 LC-1B	104	6 Hours		Flex Beam				
123 LC-1B	105	6 Hours		Flex Beam				
123 LC-1B	106	24 Hours		Flex Beam				
123 LC-1B	107	24 Hours		Flex Beam				
123 LC-1B	108	28 Days		Flex Beam				
123 LC-1B	109	28 Days		Flex Beam				
We need 3.5 cubic feet to cast 8 flexural beams								
Made 6 cu ft for consistency								
So, we need 3 sacks of DOT Cement for 6 cubic feet (to keep it sack quantities)								
Each 50-lb sack of DOT Cement requires:								
2.0 gallons water, 100 lbs concrete sand, and 150 pounds #57 stone per RapidSet.								
1 25-gram bag of RapidSet retarder per DOT Cement sack to retard 20 minutes.								
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket, retarder in 2/3 bucket.								
Sand and stone in mixer first. Add 2/3 bucket water with retarder.								
Add DOT Cement. Mix 2 to 3 minutes.								
Add additional water to bring to goal of				Goal: 5 +- 1" slump				
For 6 cubic Feet								
Use Rock-and-Tilt Mixer								
	Water	58.3 pounds to copy Batch # 1						
	Retarder	3 25-gram bags						
	DOT Cement	3 sacks						
	MMC Conc. Sand	300 lbs	CMB Lab stock					
	# 57 Limestone	450 lbs	CMB Lab stock					
	Goal: 5 +- 1" slump							

	LARGE Crater Repair Project					**Date**	15-May-06	
					Batch size:	**4.00**	**cu. Ft.**	
Material Name:		**RapidSet - DOT Cement**				**Elevated**		
		CMB checkin number		**# 060132**				
Time Cast:	0905 Hours			**Total Mixing Time:**		3 minutes		
Variable Temp Room:		90 F	**Water Temp.:**		89 F	**Material Temp.:**		91 F
6x12 cyl for compressive					**Initial Set:**	128 minutes		
Specimen Labels	Specimen Number	Test Time			**Final Set:**	160 minutes		
135 LC-2B	166	2 Hours	Strength		Mixture heavily retarded			
135 LC-2B	167	2 Hours	Strength					
135 LC-2B	168	2 Hours	Strength					
135 LC-2B	169	6 Hours	Strength					
135 LC-2B	170	6 Hours	Strength					
135 LC-2B	171	6 Hours	Strength					
135 LC-2B	172	24 Hours	Strength					
135 LC-2B	173	24 Hours	Strength					
135 LC-2B	174	24 Hours	Strength					
135 LC-2B	175	28 Days	Strength					
135 LC-2B	176	28 Days	Strength					
135 LC-2B	177	28 Days	Strength					
Due to the portable revolving-drum mixer capacity limitations, we can only cast 4.0 cubic feet.								
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack yields 2.0 cu. Ft. with added aggregates								
We will mix in sack lots for consistancy.								
So, for 4.0 cu ft we need 2 sacks of DOT Cement (to keep it sack quantities)								
Each DOT Cement sack requires:								
2.0 gallons water, 100 lbs concrete sand, and 150 pounds #57 stone per RapidSet.								
At 90 F, 4 bags of retarder per sack or 8 bags total to retard an extra 20 minutes per Rapid Set.								
Use Drum Mixer		For 4.0 cubic feet:						
	Gallons Water	4	33.3	pounds of water				
	Retarder	8, 25-gram bagslittle bags						
	DOT Cement	2 sacks						
	MMC Conc. Sand	200 lbs	CMB Lab stock					
	# 57 Limestone	300 lbs	CMB Lab stock					
	Goal: 5 +- 1" slump							
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket, retarder in 2/3 bucket.								
Sand and stone in mixer first. Add 2/3 bucket water with retarder. Add DOT Cement.								
Mix 2 to 3 minutes. Add additional water to bring to goal of						**Goal: 5 +- 1" slump**		

	LARGE Crater Repair Project					Date	15-May-06		
					Batch size:	4.00	cu. Ft.		
Material Name:		RapidSet - DOT Cement				Elevated			
		CMB checkin number		# 060132					
Time Cast:	0950 Hours			Total Mixing Time:		3 minutes			
Variable Temp Room:		90 F	Water Temp.:		89 F	Material Temp.:		91 F	
6x12 cyl for compressive									
Specimen Labels	Specimen Number	Test Time							
135 LC-2B	178	2 Hours	Modulus		1.0 gallons water added to increase slump				
135 LC-2B	179	2 Hours	Modulus		Total water this batch, 41.6 pounds				
135 LC-2B	180	2 Hours	Modulus		Mixture heavily retarded				
135 LC-2B	181	6 Hours	Modulus						
135 LC-2B	182	6 Hours	Modulus						
135 LC-2B	183	6 Hours	Modulus						
135 LC-2B	184	24 Hours	Modulus						
135 LC-2B	185	24 Hours	Modulus						
135 LC-2B	186	24 Hours	Modulus						
135 LC-2B	187	28 Days	Modulus						
135 LC-2B	188	28 Days	Modulus						
135 LC-2B	189	28 Days	Modulus						
Due to the portable revolving-drum mixer capacity limitations, we can only cast 4.0 cubic feet.									
We need 2.4 cubic feet to cast 12, 6x12 cylinders									
Each sack yields 2.0 cu. Ft. with added aggregates									
We will mix in sack lots for consistancy.									
So, for 4.0 cu ft we need 2 sacks of DOT Cement (to keep it sack quantities)									
Each DOT Cement sack requires:									
2.0 gallons water, 100 lbs concrete sand, and 150 pounds #57 stone per RapidSet.									
At 90 F, 4 bags of retarder per sack or 8 bags total to retard an extra 20 minutes per Rapid Set.									
Use Drum Mixer		For 4.0 cubic feet:							
	Gallons Water	4	33.3	pounds of water					
	Retarder	8, 25-gram bags							
	DOT Cement	2 sacks							
	MMC Conc. Sand	200 lbs	CMB Lab stock						
	# 57 Limestone	300 lbs	CMB Lab stock						
	Goal: 5 +- 1" slump								
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket, retarder in 2/3 bucket.									
Sand and stone in mixer first. Add 2/3 bucket water with retarder. Add DOT Cement.									
Mix 2 to 3 minutes. Add additional water to bring to goal of						Goal: 5 +- 1" slump			

	LARGE Crater Repair Project					Date	15-May-06	
					Batch size:	4.00	cu. Ft.	
Material Name:		RapidSet - DOT Cement				Elevated		
		CMB checkin number		# 060132				
Time Cast:	1050 Hours			Total Mixing Time:		3 minutes		
Variable Temp Room:		95 F	Water Temp.:		87 F	Material Temp.:		90 F
					Initial Set:	135 minutes		
6x12 cyl for compressive					Final Set:	176 minutes		
Specimen Labels	Specimen Number	Test Time						
135 LC-2B	190	2 Hours	Flex		0.5 gallons water added to increase slump			
135 LC-2B	191	2 Hours	Flex		Total water this batch, 37.5 pounds			
135 LC-2B	192	6 Hours	Flex		Mixture heavily retarded			
135 LC-2B	193	6 Hours	Flex					
135 LC-2B	194	24 Hours	Flex					
135 LC-2B	195	24 Hours	Flex					
135 LC-2B	196	28 days	Flex					
135 LC-2B	197	28 Days	Flex					
Due to the portable revolving-drum mixer capacity limitations, we can only cast 4.0 cubic feet.								
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack yields 2.0 cu. Ft. with added aggregates								
We will mix in sack lots for consistancy.								
So, for 4.0 cu ft we need 2 sacks of DOT Cement (to keep it sack quantities)								
Each DOT Cement sack requires:								
2.0 gallons water, 100 lbs concrete sand, and 150 pounds #57 stone per RapidSet.								
At 90 F, 4 bags of retarder per sack or 8 bags total to retard an extra 20 minutes per Rapid Set.								
Use Drum Mixer		For 4.0 cubic feet:						
	Gallons Water	4	33.3	pounds of water				
	Retarder	8, 25-gram bags						
	DOT Cement	2 sacks						
	MMC Conc. Sand	200 lbs	CMB Lab stock					
	# 57 Limestone	300 lbs	CMB Lab stock					
	Goal: 5 +- 1" slump							
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket, retarder in 2/3 bucket.								
Sand and stone in mixer first. Add 2/3 bucket water with retarder. Add DOT Cement.								
Mix 2 to 3 minutes. Add additional water to bring to goal of						Goal: 5 +- 1" slump		

	Large Crater Repair Project - Hardened Data				**Ambient**		
	Material Name:	RapidSet - DOT Cement					
Casting & Curing Temp:		Ambient, Nominally 70 degrees F			CMB Checkin # 060132		
	Date Cast:	3-May-06					
	Time,Materials in Mixer :	0840 Hours	0953 Hours				
	Initial Time of Set:	60 minutes	62 Minutes				
	Final Time of Set:	80 minutes	73 Minutes				
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
123 LC-1B	78	2 hours	4180				
123 LC-1B	79	2 hours	4660				
123 LC-1B	80	2 hours	4850				
123 LC-1B	81	6 Hours	7090				
123 LC-1B	82	6 Hours	7390				
123 LC-1B	83	6 Hours	7420				
123 LC-1B	84	24 Hours	8440				
123 LC-1B	85	24 Hours	8700				
123 LC-1B	86	24 Hours	8520	Modulus	Uncon.		
123 LC-1B	87	28 Days	11070	of	Comp.		
123 LC-1B	88	28 Days	10990	Elasticity	Strength		
123 LC-1B	89	28 Days	10320	psi	psi		
123 LC-1B	90	2 hours		5.40xE6	5270		
123 LC-1B	91	2 hours		5.50xE6	5580		
123 LC-1B	92	2 hours		5.65xE6	5790		
123 LC-1B	93	6 Hours		6.25xE6	7430		
123 LC-1B	94	6 Hours		6.20xE6	7150		
123 LC-1B	95	6 Hours		6.45xE6	7240		
123 LC-1B	96	24 Hours		7.85xE6	8540		
123 LC-1B	97	24 Hours		6.70xE6	8690		
123 LC-1B	98	24 Hours		6.65xE6	8790		
123 LC-1B	99	28 Days		6.50xE6	10950	Flexural	
123 LC-1B	100	28 Days		6.95xE6	11420	Strength	
123 LC-1B	101	28 Days		not tested	not tested	psi	
123 LC-1B	102	2 hours				445	
123 LC-1B	103	2 hours				600	
123 LC-1B	104	6 Hours				785	
123 LC-1B	105	6 Hours				705	
123 LC-1B	106	24 Hours				785	
123 LC-1B	107	24 Hours				845	
123 LC-1B	108	28 Days				860	
123 LC-1B	109	28 Days				795	

	Large Crater Repair Project - Hardened Data				**Elevated**		
Material Name:		RapidSet - DOT Cement					
Casting & Curing Temp:		Elevated Nominally 90 degrees F			CMB Checkin # 060132		
Date Cast:		15-May-06					
Time,Materials in Mixer :		0905 Hours	0950 Hours	1050 Hours			
Initial Time of Set:		128 Minutes		135 Minutes			
Final Time of Set:		160 Minutes		176 Minutes			
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
135 LC-2B	166	4 Hours	1680				
135 LC-2B	167	4 Hours	2080				
135 LC-2B	168	4 Hours	1900				
135 LC-2B	169	6 Hours	3470				
135 LC-2B	170	6 Hours	3600				
135 LC-2B	171	6 Hours	2970				
135 LC-2B	172	24 Hours	5040				
135 LC-2B	173	24 Hours	5170				
135 LC-2B	174	24 Hours	5000	Modulus	Uncon.		
135 LC-2B	175	28 Days	7870	of	Comp.		
135 LC-2B	176	28 Days	8120	Elasticity	Strength		
135 LC-2B	177	28 Days	7630	psi	psi		
135 LC-2B	178	3.5 hours		3.85xE6	1370		
135 LC-2B	179	3.5 hours		3.95xE6	1490		
135 LC-2B	180	3.5 hours		4.95xE6	1920		
135 LC-2B	181	6 Hours		5.30xE6	4140		
135 LC-2B	182	6 Hours		5.15xE6	4330		
135 LC-2B	183	6 Hours		5.35xE6	4250		
135 LC-2B	184	24 Hours		5.95xE6	5780		
135 LC-2B	185	24 Hours		5.95xE6	5860		
135 LC-2B	186	24 Hours		5.90xE6	5830		
135 LC-2B	187	28 Days		6.60xE6	8410	Flexural	
135 LC-2B	188	28 Days		6.35xE6	8500	Strength	
135 LC-2B	189	28 Days		6.35xE6	8400	psi	
135 LC-2B	190					no test	broke
135 LC-2B	191	3 Hours				130	
135 LC-2B	192	6 Hours				525	
135 LC-2B	193	6 Hours				480	
135 LC-2B	194	24 Hours				690	
135 LC-2B	195	24 Hours				655	
135 LC-2B	196	28 Days				670	
135 LC-2B	197	28 Days				635	

	LARGE Crater Repair Project					**Date**	**20-Jun-06**	
					Batch size:	**2.70**	**cu. Ft.**	
Material Name:		**CeraTech Inc. - PaveMend EX-H**				**Ambient**		
		CMB checkin number		**# 060143**				
Time Cast:	0900 Hours			**Total Mixing Time:**		10 Minutes		
Lab Ambient Temp.:		68 F	**Water Temp.:**		72 F	**Material Temp.:**		68 F
6x12 cyl for compressive								
Specimen Labels	Specimen Number	Test Time						
171 LC-1I	308	2 Hours	Strength					
171 LC-1I	309	2 Hours	Strength					
171 LC-1I	310	2 Hours	Strength					
171 LC-1I	311	6 Hours	Strength					
171 LC-1I	312	6 Hours	Strength					
171 LC-1I	313	6 Hours	Strength					
171 LC-1I	314	24 Hours	Strength					
171 LC-1I	315	24 Hours	Strength					
171 LC-1I	316	24 Hours	Strength					
171 LC-1I	317	28 Days	Strength					
171 LC-1I	318	28 Days	Strength					
171 LC-1I	319	28 Days	Strength					
Mr. Sampson oversaw and guided all mixing of this material.								
Mixture proportion from Paul Sampson, Cera Tech.								
1.35 cubic feet yield								
Pavemend EX-H		112	lbs					
ASTM # 57 limestone		80	lbs					
Water		13.2	lbs					
To cast 12, 6x12s we need to produce 2.4 cubic feet plus TOS casting.								
1.35 x 2 = 2.7 cubic feet								
Pavemend EX-H		224	lbs					
ASTM # 57 limestone		160	lbs	CMB Lab Stock				
Water		26.4	lbs					

	LARGE Crater Repair Project					Date	20-Jun-06	
					Batch size:	2.70	cu. Ft.	
Material Name:		CeraTech Inc. - PaveMend EX-H				Ambient		
		CMB checkin number		# 060143				
Time Cast:	0925 Hours			Total Mixing Time:		10 Minutes		
Lab Ambient Temp.:		68 F	Water Temp.:		72 F	Material Temp.:		68 F
6x12 cyl for compressive								
Specimen Labels	Specimen Number	Test Time						
171 LC-1I	320	2 Hours	Modulus					
171 LC-1I	321	2 Hours	Modulus					
171 LC-1I	322	2 Hours	Modulus					
171 LC-1I	323	6 Hours	Modulus					
171 LC-1I	324	6 Hours	Modulus					
171 LC-1I	325	6 Hours	Modulus					
171 LC-1I	326	24 Hours	Modulus					
171 LC-1I	327	24 Hours	Modulus					
171 LC-1I	328	24 Hours	Modulus					
171 LC-1I	329	28 Days	Modulus					
171 LC-1I	330	28 Days	Modulus					
171 LC-1I	331	28 Days	Modulus					
Mr. Sampson oversaw and guided all mixing of this material.								
Mixture proportion from Paul Sampson, Cera Tech.								
1.35 cubic feet yield								
Pavemend EX-H		112	lbs					
ASTM # 57 limestone		80	lbs					
Water		13.2	lbs					
To cast 12, 6x12s we need to produce 2.4 cubic feet plus TOS casting.								
1.35 x 2 = 2.7 cubic feet								
Pavemend EX-H		224	lbs					
ASTM # 57 limestone		160	lbs	CMB Lab Stock				
Water		26.4	lbs					

	LARGE Crater Repair Project					Date	20-Jun-06	
					Batch size:	2.70	cu. Ft.	
Material Name:		CeraTech Inc. - PaveMend EX-H				Ambient		
		CMB checkin number		# 060143				
Time Cast:	0940 Hours			Total Mixing Time:		10 Minutes		
Lab Ambient Temp.:		68 F	Water Temp.:		72 F	Material Temp.:		68 F
6x12 cyl for compressive								
Specimen Labels	Specimen Number	Test Time						
171 LC-1I	332	2 Hours	Flex Beam					
171 LC-1I	333	2 Hours	Flex Beam					
171 LC-1I	334	6 Hours	Flex Beam					
171 LC-1I	335	6 Hours	Flex Beam					
171 LC-1I	336	24 Hours	Flex Beam					
171 LC-1I	337	24 Hours	Flex Beam					
171 LC-1I	338	28 Days	Flex Beam					
171 LC-1I	339	28 Days	Flex Beam					
Mr. Sampson oversaw and guided all mixing of this material.								
Mixture proportion from Paul Sampson, Cera Tech.								
1.35 cubic feet yield								
Pavemend EX-H		112	lbs					
ASTM # 57 limestone		80	lbs					
Water		13.2	lbs					
To cast 8, 6x6x21 Beams, need 3.5 cubic feet								
1.35 x 3 = 4.05 cubic feet								
Pavemend EX-H		336	lbs					
ASTM # 57 limestone		240	lbs	CMB Lab Stock				
Water		39.6	lbs					

	LARGE Crater Repair Project					**Date**	**21-Jun-06**	
					Batch size:	**2.70**	**cu. Ft.**	
Material Name:		**CeraTech Inc. - PaveMend EX-H**				**Elevated**		
		CMB checkin number		**# 060143**				
Time Cast:	0915 Hours			**Total Mixing Time:**		10 Minutes		
Variable Temp Room:		94 F	**Water Temp.:**		87 F	**Material Temp.:**		94 F
6x12 cyl for compressive								
Specimen Labels	Specimen Number	Test Time			**Intial Set:**	35 Minutes		
					Final Set:	58 Minutes		
172 LC-2I	352	2 Hours	Strength					
172 LC-2I	353	2 Hours	Strength					
172 LC-2I	354	2 Hours	Strength					
172 LC-2I	355	6 Hours	Strength					
172 LC-2I	356	6 Hours	Strength					
172 LC-2I	357	6 Hours	Strength					
172 LC-2I	358	24 Hours	Strength					
172 LC-2I	359	24 Hours	Strength					
172 LC-2I	360	24 Hours	Strength					
172 LC-2I	361	28 Days	Strength					
172 LC-2I	362	28 Days	Strength					
172 LC-2I	363	28 Days	Strength					
Mr. Sampson oversaw and guided all mixing of this material.								
Mixture proportion from Paul Sampson, Cera Tech.								
1.35 cubic feet yield								
Pavemend EX-H		112	lbs					
ASTM # 57 limestone		80	lbs					
Water		13.2	lbs					
To cast 12, 6x12s we need to produce 2.4 cubic feet plus TOS casting.								
1.35 x 2 = 2.7 cubic feet								
Pavemend EX-H		224	lbs					
ASTM # 57 limestone		160	lbs	CMB Lab Stock				
Water		26.4	lbs					

	LARGE Crater Repair Project					**Date**	**21-Jun-06**	
					Batch size:	**2.70**	**cu. Ft.**	
Material Name:		**CeraTech Inc. - PaveMend EX-H**				**Elevated**		
		CMB checkin number		**# 060143**				
Time Cast:	0950 Hours			**Total Mixing Time:**		10 Minutes		
Variable Temp Room:		94 F	**Water Temp.:**		87 F	**Material Temp.:**		94 F
6x12 cyl for modulus								
Specimen Labels	Specimen Number	Test Time			**Intial Set:**	40 minutes		
					Final Set:	71 minutes		
172 LC-2I	364	2 Hours	Modulus					
172 LC-2I	365	2 Hours	Modulus					
172 LC-2I	366	2 Hours	Modulus					
172 LC-2I	367	6 Hours	Modulus					
172 LC-2I	368	6 Hours	Modulus					
172 LC-2I	369	6 Hours	Modulus					
172 LC-2I	370	24 Hours	Modulus					
172 LC-2I	371	24 Hours	Modulus					
172 LC-2I	372	24 Hours	Modulus					
172 LC-2I	373	28 Days	Modulus					
172 LC-2I	~~374~~	28 Days	Modulus	Not Cast, ran out of material ude to missing aggregate				
172 LC-2I	~~375~~	28 Days	Modulus	Not Cast, ran out of material ude to missing aggregate				
Mr. Sampson oversaw and guided all mixing of this material.								
Mixture proportion from Paul Sampson, Cera Tech.								
1.35 cubic feet yield								
Pavemend EX-H		112	lbs					
ASTM # 57 limestone		80	lbs					
Water		13.2	lbs					
To cast 12, 6x12s we need to produce 2.4 cubic feet plus TOS casting.								
1.35 x 2 = 2.7 cubic feet								
Pavemend EX-H		224	lbs					
ASTM # 57 limestone		160	lbs	CMB Lab Stock				
Water		26.4	lbs					
This batch missing 65.0 pounds # 57 stone. Batching error.								

	Large Crater Repair Project - Hardened Data				**Ambient**		
	Material Name:	Cera Tech - Pavemend EX-H					
Casting & Curing Temp:		Ambient, Nominally 70 degrees F			CMB Checkin # 060143		
	Date Cast:	20-Jun-06					
Time,Materials in Mixer :		0900 hours	0925 hours	0940 hours			
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
			Uncon.				
		Test	Comp.				
Specimen	Specimen	Time	Strength				
Labels	Number	or Age	psi				
171 LC-1I	308	2 Hours	60				
171 LC-1I	309	6 Hours	90				
171 LC-1I	310	6 Hours	90				
171 LC-1I	311	24 Hours	2660				
171 LC-1I	312	24 Hours	2620				
171 LC-1I	313	24 Hours	2400				
171 LC-1I	314	28 Days	4370				
171 LC-1I	315	28 Days	4340				
171 LC-1I	316	28 Days	4400	Modulus	Uncon.		
171 LC-1I	317	Extra		of	Comp.		
171 LC-1I	318	Extra		Elasticity	Strength		
171 LC-1I	319	Extra		psi	psi		
171 LC-1I	320	6 Hours		0.20 x E6	90		
171 LC-1I	321	6 Hours		0.15 x E6	90		
171 LC-1I	322	6 Hours		0.10 x E6	90		
171 LC-1I	323	24 Hours		2.70 x E6	2700		
171 LC-1I	324	24 Hours		2.65 x E6	2560		
171 LC-1I	325	24 Hours		3.00 x E6	2530		
171 LC-1I	326	28 Days		3.75 x E6	4380		
171 LC-1I	327	28 Days		3.90 x E6	4310		
171 LC-1I	328	28 Days		3.75 x E6	4220		
171 LC-1I	329	Extra				Flexural	
171 LC-1I	330	Extra				Strength	
171 LC-1I	331	Extra				psi	
171 LC-1I	332	2 Hours				Broke in Handling	
171 LC-1I	333	2 Hours				Broke in Handling	
171 LC-1I	334	24 Hours				105	
171 LC-1I	335	24 Hours				130	
171 LC-1I	336	28 Days				225	
171 LC-1I	337	28 Days				310	
171 LC-1I	338	Extra					
171 LC-1I	339	Extra					

	Large Crater Repair Project - Hardened Data				**Elevated**		
	Material Name:	Cera Tech - Pavemend EX-H					
Casting & Curing Temp:		Elevated, Nominally 90 F			CMB Checkin # 060143		
	Date Cast:	21-Jun-06					
Time,Materials in Mixer :		0915 Hours	0950 hours	1015 hours			
	Initial Set:	35 Minutes	40 minutes				
	Final Set:	58 Minutes	71 Minutes				
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
171 LC-1I	352	2 Hours	150				
171 LC-1I	353	2 Hours	150				
171 LC-1I	354	2 Hours	160				
171 LC-1I	355	6 Hours	1710				
171 LC-1I	356	6 Hours	1920				
171 LC-1I	357	6 Hours	1620				
171 LC-1I	358	24 Hours	3830				
171 LC-1I	359	24 Hours	3680				
171 LC-1I	360	24 Hours	3840	Modulus	Uncon.		
171 LC-1I	361	28 Days	7950	of	Comp.		
171 LC-1I	362	28 Days	7780	Elasticity	Strength		
171 LC-1I	363	28 Days	8090	psi	psi		
171 LC-1I	364	2 Hours		0.40 x E6	110		
171 LC-1I	365	2 Hours		0.30 x E6	110		
171 LC-1I	366	2 Hours		0.35 x E6	100		
171 LC-1I	367	6 Hours		1.45 x E6	570		
171 LC-1I	368	6 Hours		1.50 x E6	690		
171 LC-1I	369	6 Hours		2.20 x E6	1250		
171 LC-1I	370	24 Hours		3.15 x E6	3870		
171 LC-1I	371	24 Hours		3.10 x E6	3900		
171 LC-1I	372	28 Days		4.98 x E6	8020		
171 LC-1I	373	28 Days		5.20 x E6	7800	Flexural	
171 LC-1I	374	Not Cast				Strength	
171 LC-1I	375	Not Cast				psi	
171 LC-1I	376	2 Hours				80	
171 LC-1I	377	2 Hours				85	
171 LC-1I	378	6 Hours				225	
171 LC-1I	379	6 Hours				230	
171 LC-1I	380	24 Hours				350	
171 LC-1I	381	24 Hours				365	
171 LC-1I	382	28 Days				550	
171 LC-1I	383	28 Days				560	

	LARGE Crater Repair Project					**Date**	**3-Aug-06**	
					Batch size:	**3.15**	**cu. Ft.**	
Material Name:		**Thoroc 10-61 Repair Mortar**						
		CMB checkin number		**# 060170**				
Time Cast:	0835 Hours			**Total Mixing Time:**		4 Minutes		
Lab Ambient Temp.:		67 F	**Water Temp.:**		68 F	**Material Temp.:**		70 F
6x12 cyl for compressive & modulus					**Initial Set:**	193 minutes		
Specimen	Specimen	Test			**Final Set:**	200 minutes		
Labels	Number	Time						
215 LC-1N	464	2 Hours	Strength		Portable Mortar Mixer			
215 LC-1N	465	2 Hours	Strength		Added 5.0 gallons water @ 1 minute mixing			
215 LC-1N	466	2 Hours	Strength		water mass / mortar mass ratio is now 0.13			
215 LC-1N	467	6 Hours	Strength					
215 LC-1N	468	6 Hours	Strength					
215 LC-1N	469	6 Hours	Strength					
215 LC-1N	470	24 Hours	Strength					
215 LC-1N	471	24 Hours	Strength					
215 LC-1N	472	24 Hours	Strength					
215 LC-1N	473	28 Days	Strength					
215 LC-1N	474	28 Days	Strength					
215 LC-1N	475	28 Days	Strength					
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack with 56% extension of rock yields approx. 0.63 cu. Ft.								
(56% extension mimics the amount of rock used in placement in FL)								
So, for 2.4 cu ft, we need 5 sacks for 3.15 cubic feet (to keep it sack quantities) and cast a TOS								
For 56% replacement of stone, each 50-lb sack of 10-61 requires 28 pounds of #89 stone								
5 sacks *28 pounds rock per sack of mortar =					**140 pounds # 89 stone**			
Water - 0.11 water mass to dry mortar mass as dictated by guidance in Degussa literature								
5 sacks mortar = 250 lbs								
	32.5	actual water						
Water	**~~27.5~~**	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	**250**	pounds						
#89 stone	**140**	pounds		slump goal - 3" to 5 "				

	LARGE Crater Repair Project					**Date**	3-Aug-06	
					Batch size:	**3.15**	**cu. Ft.**	
Material Name:		**Thoroc 10-61 Repair Mortar**						
		CMB checkin number		**# 060170**				
Time Cast:	0900 Hours			**Total Mixing Time:**		4 Minutes		
Lab Ambient Temp.:		67 F	**Water Temp.:**		68 F	**Material Temp.:**		71 F
6x6x21 inch prisms for Flexural Strength					Initial Set:	187 Minutes		
					Final Set:	193 Minutes		
Specimen	Specimen	Test						
Labels	Number	Time				Portable Mortar Mixer		
215 LC-1N	476	2 Hours		Modulus				
215 LC-1N	477	2 Hours		Modulus	Used increased water amount from Batch #1			
215 LC-1N	478	2 Hours		Modulus				
215 LC-1N	479	6 Hours		Modulus				
215 LC-1N	480	6 Hours		Modulus				
215 LC-1N	481	6 Hours		Modulus				
215 LC-1N	482	24 Hours		Modulus				
215 LC-1N	483	24 Hours		Modulus				
215 LC-1N	484	24 Hours		Modulus				
215 LC-1N	485	28 Days		Modulus				
215 LC-1N	486	28 Days		Modulus				
215 LC-1N	487	28 Days		Modulus				
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack with 56% extension of rock yields approx. 0.63 cu. Ft.								
(56% extension mimics the amount of rock used in placement in FL)								
So, for 2.4 cu ft, we need 5 sacks for 3.15 cubic feet (to keep it sack quantities) and cast a TOS								
For 56% replacement of stone, each 50-lb sack of 10-61 requires 28 pounds of #89 stone								
5 sacks *28 pounds rock per sack of mortar =					140 pounds # 89 stone			
Water - 0.13 water mass / mortar mass based on Batch # 1 results								
5 sacks mortar = 250 lbs								
Water	32.5	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	250	pounds						
#89 stone	140	pounds		slump goal - 3" to 5 "				

	LARGE Crater Repair Project					**Date**	3-Aug-06	
					Batch size:	**4.41**	**cu. Ft.**	
Material Name:		**Thoroc 10-61 Repair Mortar**						
		CMB checkin number		**# 060170**				
Time Cast:	0935 Hours			**Total Mixing Time:**		4 Minutes		
Lab Ambient Temp.:		68 F	**Water Temp.:**		72	**Material Temp.:**		71 F
6x6x21 inch prisms for Flexural Strength					Initial Set:	--		
					Final Set:	--		
Specimen Labels	Specimen Number	Test Time			Used Portable, horizontal-blade mixer			
215 LC-1N	488	2 Hours	Flex					
215 LC-1N	489	2 Hours	Flex		Used the 0.13 water mass / mortar mass ratio			
215 LC-1N	490	6 Hours	Flex					
215 LC-1N	491	6 Hours	Flex					
215 LC-1N	492	24 Hours	Flex					
215 LC-1N	493	24 Hours	Flex					
215 LC-1N	494	28 Days	Flex					
215 LC-1N	495	28 Days	Flex					
We need 3.5 cubic feet to cast 8 flexural beams								
Each sack with 56% replacement rock yields approx. 0.63 cu. Ft.								
So, for 3.5 cu ft, we need 7 sacks for 4.41 cubic feet (to keep it sack quantities) and cast TOS								
For 56% replacement of stone, each sack of 10-61 requires 28 pounds stone								
7 sacks * 28 pounds rock per sack =				**196 pounds rock**				
Water - 0.13 water mass / mortar mass								
	45.5	pounds water						
Water	**~~38.5~~**	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	**350**	pounds	7 Sacks					
#89 stone	**196**	pounds		slump goal - 3" to 5 "				

	LARGE Crater Repair Project					**Date**	**10-Jul-06**	
					Batch size:	**3.35**	**cu. Ft.**	
Material Name:		**Thoroc 10-61 repair mortar**						
			CMB checkin number	**# 060170**				
Time Cast:	0915 Hours			**Total Mixing Time:**		4 minutes		
Variable Temp. Room:		89 F		**Water Temp.:**	88 F	**Material Temp.:**		90 F
6x12 cyl for compressive					**Initial Set:**			
					Final Set:			
Specimen Labels	Specimen Number	Test Time						
191 LC-2N	396	2 Hours	Strength		Dry. Not mixing well.			
191 LC-2N	397	2 Hours	Strength		Added addtional water, 5.2 pounds			
191 LC-2N	398	2 Hours	Strength		0" Slump			
191 LC-2N	399	6 Hours	Strength		Heavy vibration needed to place in molds			
191 LC-2N	400	6 Hours	Strength		Too stiff for T.O.S.			
191 LC-2N	401	6 Hours	Strength					
191 LC-2N	402	24 Hours	Strength		Original water/dry mortar mass ratio = .11			
191 LC-2N	403	24 Hours	Strength		After addition of water:			
191 LC-2N	404	24 Hours	Strength		Water mass / mortar mass ratio = .135			
191 LC-2N	405	28 Days	Strength					
191 LC-2N	406	28 Days	Strength					
191 LC-2N	407	28 Days	Strength					
Used Portable, horizontal-blade mixer								
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack with 75% replacement rock yields approx. 0.67 cu. Ft.								
75% replacement based on recommendation by Doc Watson of Degussa								
So, for 2.4 cu ft, we need 5 sacks for 3.35 cubic feet (to keep it sack quantities) and cast TOS								
For 75% replacement of stone, each <u>sack</u> of 10-61 requires 37.5 pounds stone								
5 sacks * 37.5 pounds rock per sack =				**187.5 pounds rock**				
Water - 5.5 pints per sack to start. 5.5 pints * 5 sacks =					27.5 pints			
27.5 pints of water or 3.44 gallons. 3.44 gallons water = 28.65 pounds								
	33.85	pounds						
Water	**~~28.65~~**	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	**250**	pounds		Can add up to additional 5.2 pounds water for slump				
#89 stone	**187.5**	pounds		slump goal - 3" to 5 "				

	LARGE Crater Repair Project					Date	10-Jul-06	
					Batch size:	3.35	cu. Ft.	
Material Name:		Thoroc 10-61 repair mortar						
			CMB checkin number	# 060170				
Time Cast:	0950 Hours			Total Mixing Time:		4 minutes		
Variable Temp. Room:		90 F		Water Temp.:	87 F	Material Temp.:		91 F
6x12 cyl for compressive					Initial Set:			
					Final Set:	86 minutes		
Specimen Labels	Specimen Number	Test Time						
191 LC-2N	408	2 Hours	Modulus		Added 1.0 pounds additional water			
191 LC-2N	409	2 Hours	Modulus		But, this 1.0 pound made the mixture too wet.			
191 LC-2N	410	2 Hours	Modulus		water mass/mortar mass for this batch =.15			
191 LC-2N	411	6 Hours	Modulus					
191 LC-2N	412	6 Hours	Modulus					
191 LC-2N	413	6 Hours	Modulus					
191 LC-2N	414	24 Hours	Modulus					
191 LC-2N	415	24 Hours	Modulus					
191 LC-2N	416	24 Hours	Modulus					
191 LC-2N	417	28 Days	Modulus					
191 LC-2N	418	28 Days	Modulus					
191 LC-2N	419	28 Days	Modulus					
Used Portable, horizontal-blade mixer								
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack with 75% replacement rock yields approx. 0.67 cu. Ft.								
75% replacement based on recommendation by Doc Watson of Degussa								
So, for 2.4 cu ft, we need 5 sacks for 3.35 cubic feet (to keep it sack quantities) and cast TOS								
For 75% replacement of stone, each sack of 10-61 requires 37.5 pounds stone								
5 sacks * 37.5 pounds rock per sack =				187.5 pounds rock				
Water - 5.5 pints per sack to start. 5.5 pints * 5 sacks =					27.5 pints			
27.5 pints of water or 3.44 gallons. 3.44 gallons water = 28.65 pounds								
However, mix 1 too dry, so we will use water amount used in Florida								
Therefore, For Batch 2, water ratio is 0.15 (water mass to mass of 10-61 mortar)								
	38.5	pounds						
Water	~~37.5~~	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	250	pounds		Add up to additional 5.2 pounds water for slump				
#89 stone	187.5	pounds		slump goal - 3" to 5 "				

	LARGE Crater Repair Project					**Date**	10-Jul-06	
					Batch size:	**4.02**	**cu. Ft.**	
Material Name:		**Thoroc 10-61 repair mortar**						
	CMB checkin number			**# 060170**				
Time Cast:	1058			**Total Mixing Time:**		4 minutes		
Variable Temp. Room:		91 F		**Water Temp.:**	89 F	**Material Temp.:**		91 F
6x12 cyl for compressive					Initial Set:			
					Final Set:	82 minutes		
Specimen Labels	Specimen Number	Test Time						
191 LC-2N	420	2 Hours	Flex					
191 LC-2N	421	2 Hours	Flex					
191 LC-2N	422	6 Hours	Flex					
191 LC-2N	423	6 Hours	Flex					
191 LC-2N	424	24 Hours	Flex					
191 LC-2N	425	24 Hours	Flex					
191 LC-2N	426	28 Days	Flex					
191 LC-2N	427	28 Days	Flex					
Used Portable, horizontal-blade mixer								
We need 3.5 cubic feet to cast 8 flexural beams								
Each sack with 75% replacement rock yields approx. 0.67 cu. Ft.								
75% replacement based on recommendation by Doc Watson of Degussa								
So, for 3.5 cu ft, we need 6 sacks for 4.02 cubic feet (to keep it sack quantities) and cast TOS								
For 75% replacement of stone, each sack of 10-61 requires 37.5 pounds stone								
6 sacks * 37.5 pounds rock per sack =				**225 pounds rock**				
Water: Mix 1 too dry, so we will use water amount used in Florida								
Therefore, For Batch 2, water ratio is 0.15 (water mass to mass of 10-61 mortar)								
Added additional 1.0 pound water to BATCH # 2. Result was too wet, so will not add this time.								
Water	**45**	pounds		Water, rock, mortar, chase water.				
10-61 Mortar	**6 Sacks**							
#89 stone	**225**	pounds		slump goal - 3" to 5 "				

	Large Crater Repair Project - Hardened Data				**Ambient**		
Material Name:		Thoroc 10-61 Repair Mortar					
Casting & Curing Temp:		Ambient, Nominally 70 degrees F			CMB Checkin # 060170		
	Date Cast:	3-Aug-06					
Time,Materials in Mixer :		0835 Hours	0900 Hours	0935 Hours			
Initial Time of Set:		193 minutes	187 Minutes				
Final Time of Set:		200 minutes	193 Minutes				
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
			Uncon.				
		Test	Comp.				
Specimen	Specimen	Time	Strength				
Labels	Number	or Age	psi				
215 LC-1N	464	4 Hours	3820				
215 LC-1N	465	4 Hours	3870				
215 LC-1N	466	4 Hours	3970				
215 LC-1N	467	6 Hours	4060				
215 LC-1N	468	6 Hours	4180				
215 LC-1N	469	6 Hours	4040				
215 LC-1N	470	24 Hours	4760				
215 LC-1N	471	24 Hours	5190				
215 LC-1N	472	24 Hours	5260	Modulus	Uncon.		
215 LC-1N	473	28 Days		of	Comp.		
215 LC-1N	474	28 Days		Elasticity	Strength		
215 LC-1N	475	28 Days		psi	psi		
215 LC-1N	476	4 Hours		4.10xE6	3520		
215 LC-1N	477	4 Hours		4.20xE6	3660		
215 LC-1N	478	4 Hours		4.20xE6	3690		
215 LC-1N	479	6 Hours		4.15xE6	3870		
215 LC-1N	480	6 Hours		4.30xE6	3910		
215 LC-1N	481	6 Hours		4.45xE6	4050		
215 LC-1N	482	24 Hours		4.60xE6	4700		
215 LC-1N	483	24 Hours		4.75xE6	4740		
215 LC-1N	484	24 Hours		4.70xE6	4810		
215 LC-1N	485	28 Days				Flexural	
215 LC-1N	486	28 Days				Strength	
215 LC-1N	487	28 Days				psi	
215 LC-1N	488	4 Hours				375	
215 LC-1N	489	4 Hours				380	
215 LC-1N	490	6 Hours				450	
215 LC-1N	491	6 Hours				400	
215 LC-1N	492	24 Hours				535	
215 LC-1N	493	24 Hours				550	
215 LC-1N	494	28 Days					
215 LC-1N	495	28 Days					

	Large Crater Repair Project - Hardened Data				**elevated**		
	Material Name:	Thoroc 10-61 Repair Mortar					
Casting & Curing Temp:		Elevated, Nominally 90 degrees F			CMB Checkin # 060170		
	Date Cast:	10-Jul-06					
Time,Materials in Mixer :		0915 Hours	0950 Hours	1058 Hours			
	Initial Time of Set:						
	Final Time of Set:		86 minutes	82 Minutes			
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
191 LC-2N	396	2 Hours	3680				
191 LC-2N	397	2 Hours	3520				
191 LC-2N	398	2 Hours	3630				
191 LC-2N	399	6 Hours	4260				
191 LC-2N	400	6 Hours	4220				
191 LC-2N	401	6 Hours	4350				
191 LC-2N	402	24 Hours	5040				
191 LC-2N	403	24 Hours	5120				
191 LC-2N	404	24 Hours	5090	Modulus	Uncon.		
191 LC-2N	405	28 Days	8260	of	Comp.		
191 LC-2N	406	28 Days	8230	Elasticity	Strength		
191 LC-2N	407	28 Days	8160	psi	psi		
191 LC-2N	408	2 Hours		3.00xE6	1830		
191 LC-2N	409	2 Hours		3.30xE6	1910		
191 LC-2N	410	2 Hours		3.60xE6	2020		
191 LC-2N	411	6 Hours		3.20xE6	2240		
191 LC-2N	412	6 Hours		3.45xE6	2320		
191 LC-2N	413	6 Hours		3.45xE6	2390		
191 LC-2N	414	24 Hours		3.30xE6	2700		
191 LC-2N	415	24 Hours		3.30xE6	2730		
191 LC-2N	416	24 Hours		3.50xE6	2890		
191 LC-2N	417	28 Days		4.25xE6	5090	Flexural	
191 LC-2N	418	28 Days		4.40xE6	5200	Strength	
191 LC-2N	419	28 Days		4.50xE6	4770	psi	
191 LC-2N	420	2 Hours				240	
191 LC-2N	421	2 Hours				170	
191 LC-2N	422	6 Hours				335	
191 LC-2N	423	6 Hours				355	
191 LC-2N	424	24 Hours				365	
191 LC-2N	425	24 Hours				420	
191 LC-2N	426	28 Days				545	
191 LC-2N	427	28 Days				610	

	LARGE Crater Repair Project					**Date**	18-Sep-06	
					Batch size:	**3.2**	**cu. Ft.**	
Material Name:		**Ultimax - Concrete - 2nd shipment**				**Ambient**		
	CMB checkin number			**# 060180**				
Time Cast:	0842 hours			**Total Mixing Time:**		3 Minutes		
Lab Ambient Temp.:		70.7 F	**Water Temp.:**		71.6 F	**Material Temp.:**		69.0 F
6x12 cyl for compressive & modulus					Initial Set:	138 minutes		
Specimen Labels	Specimen Number	Test Time			Final Set:	310 minutes		
261 LC-1P	520	2 Hours	6x12		Retarded mixture			
261 LC-1P	521	2 Hours	6x12					
261 LC-1P	522	not cast	6x12					
261 LC-1P	523	6 Hours	6x12					
261 LC-1P	524	6 Hours	6x12					
261 LC-1P	525	6 Hours	6x12					
261 LC-1P	526	24 Hours	6x12					
261 LC-1P	527	24 Hours	6x12					
261 LC-1P	528	not cast	6x12					
261 LC-1P	529	28 Days	6x12					
261 LC-1P	530	28 Days	6x12					
261 LC-1P	531	not cast	6x12					
We need 2.4 cubic feet to cast 12, 6x12 cylinders								
Each sack yields approx. 0.45 cu. Ft.								
So, for 2.4 cu ft, we need 7 sacks for 3.15 cubic feet (to keep it sack quantities)								0.25% dose
Water - Manuf. Suggests 0.12 water mass / to mass of Ultimax Concrete to start								Retarder
							Water in	"UC Delay"
Each sack is 50 lbs.		**7 sacks is 350 pounds**			Mass of Sacks	w/c	pounds	GRAMS
42 pounds water for 7 Sacks Ultimax Concrete					350	0.12	42	396.9
Can add up to 0.15 water mass to Ultimax mass or 10.5 pounds water								
Horizontal mortar mixer								
Water	**42**	pounds	1/2 water, dry materials, then rest of water.					
Ultimax	**350**	pounds						
Very Stickey mixture. Hard to discharge, but had approx. 6-inch slump								
Due to misinformnation from manufacturer on yield and stickiness of mixture, three cylinders not cast.								

	LARGE Crater Repair Project					Date	18-Sep-06		
					Batch size:		cu. Ft.		
Material Name:		Ultimax - Concrete				Ambient			
		CMB checkin number		# 060180		Casting Modulus Cylinders			
Time Cast:	0922 AM			Total Mixing Time:		3 Minutes			
Lab Ambient Temp.:		69 F	Water Temp.:		70 F	Material Temp.:		70- F	
						Initial Set:	130minutes		
Specimen Labels	Specimen Number	Test Time				Final Set:	290 minutes		
261 LC-1P	532	2 Hours		Modulus		Yield was off on Batch #1.			
261 LC-1P	533	2 Hours		Modulus		Based on Manufacturer Instructions.			
261 LC-1P	534	2 Hours		Modulus		Batch size increased for this batch.			
261 LC-1P	535	6 Hours		Modulus					
261 LC-1P	536	6 Hours		Modulus					
261 LC-1P	537	6 Hours		Modulus					
261 LC-1P	538	24 Hours		Modulus					
261 LC-1P	539	24 Hours		Modulus					
261 LC-1P	540	24 Hours		Modulus					
261 LC-1P	541	28 Days		Modulus					
261 LC-1P	542	28 Days		Modulus					
261 LC-1P	543	28 Days		Modulus					
								0.25% dose	
								Retarder	
							Water in	"UC Delay"	
Each sack is 50 lbs.		9 sacks is 350 pounds			Mass of Sacks	w/c	pounds	GRAMS	
54 pounds water for 9 Sacks Ultimax Concrete					450	0.12	54	510.3	
Use Horizontal Mortar Mixer									
Water	54	pounds	2/3 water, retarder, dry materials, then rest of water.						
Ultimax	450	pounds							

	LARGE Crater Repair Project					**Date**	18-Sep-06	
					Batch size:		**cu. Ft.**	
Material Name:		**Ultimax - Concrete**				**Ambient**		
		CMB checkin number		**# 060180**				
Time Cast:	1030 hours	Batch 1		**Total Mixing Time:**		4 minutes		
	1102	Batch 2				4 Minutes		
Lab Ambient Temp:		70	**Water Temp.:**		70	**Material Temp.:**		70
					2 Batches made for Beams			
6x12 cyl for compressive								
Specimen	Specimen	Test						
Labels	Number	Time				No retarder used		
261 LC-1P	544	2 Hours	Beams	Batch 1				
261 LC-1P	545	2 Hours	Beams	Batch 1				
261 LC-1P	546	6 Hours	Beams	Batch 1				
261 LC-1P	547	6 Hours	Beams	Batch 1				
261 LC-1P	548	24 Hours	Beams	Batch 2				
261 LC-1P	549	24 Hours	Beams	Batch 2				
261 LC-1P	550	28 Days	Beams	Batch 2				
261 LC-1P	551	28 Days	Beams	Batch 2				
So, for 3.5 cu ft, we need 16 sacks for 4.00 cubic feet (to keep it sack quantities)								
Water - Manuf. Suggests 0.12 water mass / to mass of Ultimax Concrete to start								
Will split batch. Mixer cannot make this big batch size.								Retarder
Two batches, 8 sacks each.							Water in	"UC Delay"
					Mass of Sacks	w/c	pounds	GRAMS
					400	0.12	48	453.6
Each sack is 50 lbs.		**8 sacks is 400 pounds**						
48 pounds water for 8 Sacks Ultimax Concrete								
Use Horizontal Mortar Mixer								
Water	48	pounds	1/2 water, dry materials, then rest of water.					
Ultimax	400	pounds						

	Large Crater Repair Project - Hardened Data				**Ambient**		
	Material Name:	Ultimax - Concrete					
Casting & Curing Temp:		Ambient, Nominally 70 degrees F			CMB Checkin # 060180		
	Date Cast:	18-Sep-06					
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
			Uncon.				
		Test	Comp.				
Specimen	Specimen	Time	Strength				
Labels	Number	or Age	psi				
261 LC-1P	520	2 Hours	Too weak				
261 LC-1P	521	2 Hours	Too weak				
261 LC-1P	522	2 Hours	Not cast				
261 LC-1P	523	6 Hours	2850				
261 LC-1P	524	6 Hours	3900				
261 LC-1P	525	6 Hours	4390				
261 LC-1P	526	24 Hours	7710				
261 LC-1P	527	24 Hours	8040				
261 LC-1P	528	24 Hours	Not cast	Modulus	Uncon.		
261 LC-1P	529	28 Days	9610	of	Comp.		
261 LC-1P	530	28 Days	9900	Elasticity	Strength		
261 LC-1P	531	28 Days	Not cast	psi	psi		
261 LC-1P	532	2 Hours		too weak, not tested			
261 LC-1P	533	2 Hours		too weak, not tested			
261 LC-1P	534	2 Hours		too weak, not tested			
261 LC-1P	535	6 Hours		2.75 x E6	2350		
261 LC-1P	536	6 Hours		2.65 x E6	2810		
261 LC-1P	537	7 hours		Bad test	bad test		
261 LC-1P	538	24 Hours		3.80 x E6	7980		
261 LC-1P	539	24 Hours		3.70 x E6	7980		
261 LC-1P	540	24 Hours		3.65 x E6	7770		
261 LC-1P	541	28 Days		4.45 x E6	10350	Flexural	
261 LC-1P	542	28 Days		4.60 x E6	10200	Strength	
261 LC-1P	543	28 Days		4.60 x E6	10470	psi	
261 LC-1P	544	2 Hours				too weak, not tested	
261 LC-1P	545	2 Hours				too weak, not tested	
261 LC-1P	546	6 Hours				100	
261 LC-1P	547	6 Hours				90	
261 LC-1P	548	24 Hours				290	
261 LC-1P	549	24 Hours				240	
261 LC-1P	550	28 Days				695	
261 LC-1P	551	28 Days				620	

	LARGE Crater Repair Project					**Date**	25-May-06	
					Batch size:	**6.0**	**cu. Ft.**	
Material Name:		**Ultimax - Aquacrete**				**Ambient**		
		CMB checkin number		**# 060144**				
Time Cast:	1340			**Total Mixing Time:**		4 Minutes		
Lab Ambient Temp.:		72 F	**Water Temp.:**		69 F	**Material Temp.:**		73 F
6x12 cyl for compressive & modulus					Initial Set:	75 minutes		
Specimen	Specimen	Test			Final Set:	95 minutes		
Labels	Number	Time			Retarded mixture			
145 LC-1J	200	2 Hours	Strength					
145 LC-1J	201	2 Hours	Strength		Aquacrete personnel supervised mixing			
145 LC-1J	202	2 Hours	Strength					
145 LC-1J	203	6 Hours	Strength		Batch 1			
145 LC-1J	204	6 Hours	Strength		Rock-and-Tilt Revolving-Drum Mixer			
145 LC-1J	205	6 Hours	Strength		Did not mix. Thrown out.			
145 LC-1J	206	24 Hours	Strength					
145 LC-1J	207	24 Hours	Strength		Batch 2			
145 LC-1J	208	24 Hours	Strength		Portable Horizontal motar mixer used.			
145 LC-1J	209	28 Days	Strength		Very lumpy mixture.			
145 LC-1J	210	28 Days	Strength		Added total of 15 pounds water.			
145 LC-1J	211	28 Days	Strength		After this, set up while trying to place in molds.			
145 LC-1J	212	2 Hours	Modulus		Thrown out.			
145 LC-1J	213	2 Hours	Modulus					
145 LC-1J	214	2 Hours	Modulus		Batch 3			
145 LC-1J	215	6 Hours	Modulus		Portable Horizontal motar mixer used.			
145 LC-1J	216	6 Hours	Modulus		675-grams citric acid added to retard mixture			
145 LC-1J	217	6 Hours	Modulus		Added 15 pounds water at 2 minutes mixing.			
145 LC-1J	218	24 Hours	Modulus		Sticking to paddles.			
145 LC-1J	219	24 Hours	Modulus		Discharged at 24 minutes mixing time.			
145 LC-1J	220	24 Hours	Modulus		22-second flow time.			
145 LC-1J	221	28 Days	Modulus					
145 LC-1J	222	28 Days	Modulus					
145 LC-1J	223	28 Days	Modulus					
We need 4.8 cubic feet to cast 24 6x12 cylinders								
Each sack yields approx. 0.5 cu. Ft.								
So, for 4.8 cu ft we need 12 sacks for 6 cubic feet (to keep it sack quantities)								
Each sack requires 0.25 water mass to Aquacrete mass (w/A)							Water in	
					Mass of Sacks	water/sack	pounds	
Each sack is 50 lbs.		**12 sacks is 600 pounds**			600	0.25	~~150~~	
150 pounds water for 12 Sacks Aquacrete						0.275	165 pounds total	
Use rubber-tire Mortar Mixer								

	LARGE Crater Repair Project					Date	26-May-06	
					Batch size:	4.0	cu. Ft.	
Material Name:		Ultimax - Aquacrete				Ambient		
		CMB checkin number		# 060144				
Time Cast:	0920 AM			Total Mixing Time:		3 Minutes		
Lab Ambient Temp.:		72 F	Water Temp.:		69 F	Material Temp.:		74 F
Specimen Labels	Specimen Number	Test Time						
146 LC-2B	224	2 Hours		Flex Beam				
146 LC-2B	225	2 Hours		Flex Beam				
146 LC-2B	226	6 Hours		Flex Beam				
146 LC-2B	227	6 Hours		Flex Beam				
146 LC-2B	228	24 Hours		Flex Beam				
146 LC-2B	229	24 Hours		Flex Beam				
146 LC-2B	230	28 Days		Flex Beam				
146 LC-2B	231	28 Days		Flex Beam				
We need 4.0 cubic ft for 8 beams								
Each sack of Aquacrete yields approx. 0.5 cu. Ft.								
So, we need 8 sacks of Aquacrete for 4 cubic feet (to keep it sack quantities)								
Each sack is 50 lbs.		8 sacks is 400 lbs.						
Each sack requires 0.25 water mass to Aquacrete mass								
For 4.0 cubic feet:								
Aquacrete - 400 lbs.								
Water - 100 lbs.		108 pounds water			No retarder used.			
Added additional water of 8.0 lbs. 0.27 water mass / Aquacrete mass (w/A)								
Used rubber -tire Motar Mixer								
Mixing Procedure: Split water into 1/3 bucket and 2/3 bucket								
Added 3/4 of total water, then 8 sacks of Aquacrete the the rest of batched water								
					Mass of Sacks	w/A	Water in pounds	
					400	0.25	~~100~~	
						0.27	108 pounds total	
						Extra water added		

	Large Crater Repair Project					**Date**	7-Jun-06	
					Batch size	**6**	**cu ft**	
Material Name:		**Ultimax - Aquacrete**				**Elevated**		
		CMB checkin number		**# 060144**				
Time Cast:	0930 AM			**Total Mixing Time:**		3 Minutes		
Lab Ambient Temp.:		72 F		**Water Temp.:**	87 F	**Material Temp.:**		91 F
Specimen Labels	Specimen Number	Test Time						
158 LC-2J	240	2 Hours	6x12		**Initial Set:**	30 Minutes		
158 LC-2J	241	2 Hours	6x12		**Final Set:**	40 Minutes		
158 LC-2J	242	2 Hours	6x12					
158 LC-2J	243	4 Hours	6x12		No retarder used			
158 LC-2J	244	4 Hours	6x12					
158 LC-2J	245	4 Hours	6x12					
158 LC-2J	246	24 Hours	6x12					
158 LC-2J	247	24 Hours	6x12					
158 LC-2J	248	24 Hours	6x12					
158 LC-2J	249	28 Days	6x12					
158 LC-2J	250	28 Days	6x12					
158 LC-2J	251	28 Days	6x12					
158 LC-2J	252	2 Hours	Modulus					
158 LC-2J	253	2 Hours	Modulus					
158 LC-2J	254	2 Hours	Modulus					
158 LC-2J	255	4 Hours	Modulus					
158 LC-2J	256	4 Hours	Modulus					
158 LC-2J	257	4 Hours	Modulus					
158 LC-2J	258	24 Hours	Modulus					
158 LC-2J	259	24 Hours	Modulus					
158 LC-2J	260	24 Hours	Modulus					
158 LC-2J	261	28 Days	Modulus					
158 LC-2J	262	28 Days	Modulus					
158 LC-2J	263	28 Days	Modulus					
We need 4.8 cubic feet to cast 24 6x12 cylinders								
Each sack yields approx. 0.5 cu. Ft.								
So, for 4.8 cu ft we need 12 sacks for 6 cubic feet (to keep it sack quantities)								
Each sack requires 0.25 water mass / Aquacrete mass (w/A)							Water in	
					Mass of Sacks	w/A	pounds	
Each sack is 50 lbs.		12 sacks is 600 pounds			600	0.25	~~150~~	
150 pounds water for 12 Sacks Aquacrete						0.263	158 pounds total	
Can add up to 15 pounds water						**Extra water added**		
Use rubber-tire Mortar Mixer								

	LARGE Crater Repair Project					Date	7-Jun-06	
					Batch size:	4.00	cu. Ft.	
Material Name:		Ultimax - Aquacrete				Elevated		
		CMB checkin number		# 060144				
Time Cast:	0845 Hours			Total Mixing Time:		3 minutes		
Variable Temp Room:		92 F	Water Temp.:		87 F	Material Temp.:		90 F
						Initial Set:	33 Minutes	
6x12 cyl for compressive						Final Set:	42 Minutes	
Specimen Labels	Specimen Number	Test Time				No retarder used		
158 LC-2J	232	2 Hours		Flex Beam				
158 LC-2J	233	2 Hours		Flex Beam				
158 LC-2J	234	6 Hours		Flex Beam				
158 LC-2J	235	6 Hours		Flex Beam				
158 LC-2J	236	24 Hours		Flex Beam				
158 LC-2J	237	24 Hours		Flex Beam				
158 LC-2J	238	28 Days		Flex Beam				
158 LC-2J	239	28 Days		Flex Beam				
We need 3.5 cubic ft to cast 8 flex beams								
Each sack yields approx. 0.5 cu. Ft.				Make 4.0 cubic feet.				
So, we need 8 sacks of Aquacrete for 4 cubic feet (to keep it sack quantities)								
Each sack of Aquacrete is 50 lbs.								
Each sack requires 0.25 water mass to Aquacrete mass (w/A)								
So, 8 sacks (400 pounds) x 0.25 = 100 pounds water								
Use the rubber-tire Mortar Mixer in hot room								
We added additional water of 8.0 lbs. for the ambient casting. (final w/A 0.27								
Can add up to 10 pounds of water maximum								
	Mass of Sacks	w/A	Water in pounds					
	400	0.25	~~100~~					
		0.27	108 pounds total water					
Water - 100 lbs. initially								
Aquacrete - 400 lbs.								
Mixing Procedure: Split water into 1/4 bucket and 3/4 bucket								
Added 3/4 of total water, then 8 sacks of Aquacrete then the rest of batched water								

	Large Crater Repair Project - Hardened Data				**Ambient**		
	Material Name:	Ultimax - Aquacrete					
Casting & Curing Temp:		Ambient, Nominally 70 degrees F			CMB Checkin # 060144		
	Date Cast:	25-May-06					
Time,Materials in Mixer :		1340 Hours					
Initial Time of Set:		75 minutes					
Final Time of Set:		95 minutes					
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
145 LC-1J	200	2 Hours	1430				
145 LC-1J	201	2 Hours	1840				
145 LC-1J	202	2 Hours	1980				
145 LC-1J	203	4 Hours	2410				
145 LC-1J	204	4 Hours	2480				
145 LC-1J	205	4 Hours	2610				
145 LC-1J	206	24 Hours	3270				
145 LC-1J	207	24 Hours	3070				
145 LC-1J	208	24 Hours	3260	Modulus	Uncon.		
145 LC-1J	209	28 Days	6640	of	Comp.		
145 LC-1J	210	28 Days	6370	Elasticity	Strength		
145 LC-1J	211	28 Days	6100	psi	psi		
145 LC-1J	212	2 Hours		1.10xE6	2140		
145 LC-1J	213	2 Hours		1.20xE6	1710		
145 LC-1J	214	2 Hours		1.15xE6	2230		
145 LC-1J	215	4 Hours		1.30xE6	2540		
145 LC-1J	216	4 Hours		1.30xE6	2520		
145 LC-1J	217	4 Hours		1.35xE6	2620		
145 LC-1J	218	24 Hours		1.60xE6	3440		
145 LC-1J	219	24 Hours		1.55xE6	3400		
145 LC-1J	220	24 Hours		1.55xE6	3390		
145 LC-1J	221	28 Days		2.30xE6	6970	Flexural	
145 LC-1J	222	28 Days		2.25xE6	6730	Strength	
145 LC-1J	223	28 Days		2.30xE6	7130	psi	
146 LC-1J	224	2 Hours				155	
146 LC-1J	225	2 Hours				190	
146 LC-1J	226	6 Hours				225	
146 LC-1J	227	6 Hours				250	
146 LC-1J	228	24 Hours				410	
146 LC-1J	229	24 Hours				445	
146 LC-1J	230	28 Days				230	
146 LC-1J	231	28 Days				260	

	Large Crater Repair Project - Hardened Data				**Elevated**		
Material Name:		Ultimax - Aquacrete					
Casting & Curing Temp:		Elevated, Nominally 90 F			CMB Checkin # 060144		
	Date Cast:	7-Jun-06					
Time,Materials in Mixer :		0845 Hours	0930 Hours				
Initial Time of Set:		30 Minutes	33 Minutes				
Final Time of Set:		40 Minutes	42 Minutes				
6x12 cylinders, Unconfined Compressive Strength, ASTM C 39							
6x12 cylinders, Modulus of Elasticity, ASTM C 469,							
6x6x21 Beams, Flexural Strength, ASTM C 78,							
Specimen Labels	Specimen Number	Test Time or Age	Uncon. Comp. Strength psi				
158 LC-2B	240	2 Hours	2150				
158 LC-2B	241	2 Hours	2150				
158 LC-2B	242	2 Hours	2050				
158 LC-2B	243	6 hours	2460				
158 LC-2B	244	6 hours	2530				
158 LC-2B	245	6 hours	2510				
158 LC-2B	246	24 Hours	2790				
158 LC-2B	247	24 Hours	2750				
158 LC-2B	248	24 Hours	2820	Modulus	Uncon.		
158 LC-2B	249	28 Days	5110	of	Comp.		
158 LC-2B	250	28 Days	5650	Elasticity	Strength		
158 LC-2B	251	28 Days	5040	psi	psi		
158 LC-2B	252	2 Hours		1.20xE6	1840		
158 LC-2B	253	2 Hours		1.20xE6	2190		
158 LC-2B	254	2 Hours		1.20xE6	2330		
158 LC-2B	255	6 hours		1.30xE6	2440		
158 LC-2B	256	6 hours		1.35xE6	2500		
158 LC-2B	257	6 hours		1.30xE6	2480		
158 LC-2B	258	24 Hours		1.45xE6	2780		
158 LC-2B	259	24 Hours		1.45xE6	2750		
158 LC-2B	260	24 Hours		1.45xE6	2980		
158 LC-2B	261	28 Days		2.05xE6	4830	Flexural	
158 LC-2B	262	28 Days		2.05xE6	5330	Strength	
158 LC-2B	263	28 Days		2.00xE6	5180	psi	
158 LC-2B	232	2 Hours				70	
158 LC-2B	233	2 Hours				85	
158 LC-2B	234	6 hours				205	
158 LC-2B	235	6 hours				180	
158 LC-2B	236	24 Hours				380	
158 LC-2B	237	24 Hours				330	
158 LC-2B	238	28 days				180	
158 LC-2B	239	28 days				210	

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14. ABSTRACT

Current practice for expedient runway repair dictates capping either a crushed stone or sand grid repair with a foreign object damage (FOD) cover. In recent testing, the heavy loading characteristics of transport aircraft have been shown to reduce the performance life of these types of repairs. Repairs capped with concrete are limited by time requirements, equipment, and available materials. Short set times, rapid strength gain, good durability, and satisfactory flexibility to resist the punishment of repeated heavy aircraft loads are beneficial characteristics of rapid setting cementitious materials. However, the use of these materials has been limited due to short working times, health concerns, and excessive shrinkage cracking. Improvements in rapid setting materials have allowed their use to become more common in pavement construction and repair projects, particularly when the operational tempo is critical to avoid penalty. Numerous commercial products are available. A full-scale field test was conducted using rapid setting materials to repair simulated bomb craters in an airfield. The repaired sections cured for 4 hr and were trafficked using a load cart equipped with an F-15E aircraft tire. The target service life of the repair was between 100 and 5,000 passes of the load cart. Results from this study were incorporated into Air Force guidance addressing the use of rapid setting materials for crater repair. This report describes the repair methods and performance of the rapid setting materials used in the full-scale field test to repair large craters.

15. SUBJECT TERMS

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